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An Ecological Survey of the Onion Creek Candidate Research Natural Area on the Tahoe National Forest, California

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INTRODUCTION

Onion Creek Candidate Research Natural Area encompasses 419 ha between the elevations of 1,840 and 2,555 meters on the west slope of the Sierra Nevada (Tahoe National Forest). The proposed natural area comprises the uppermost watershed of Onion Creek (a tributary of the North Fork of the American River) extending from 39° 17' 29" to 39° 22' 30" N latitude and between 120° 19' 30" and 120° 22' longitude within Onion Creek Experimental Forest (Figure 1). South, southwest, and west facing slopes are the dominant aspects, with terrain becoming steeper as elevation increases.

Unlogged stands of white fir and red fir are the predominant vegetation below 2,250 m. Above 2,250 m conifer forest gives way to vertical cliffs, talus slopes, and subalpine scree. Other vegetation types present in the proposed Onion Creek natural area are Jeffrey pine forest, mountain alder and Nuttall willow thickets, huckleberry oak scrub, and dry meadows. This study presents a general ecological description of vegetation within the proposed natural area emphasizing composition, growth rates, and structure of coniferous vegetation types.

PROCEDURE

Vegetation was field mapped according to dominant species and results transcribed onto an enlarged 7½ minute series U.S. Geological Survey topographic sheet for Norden. Sites

believed representative of forest vegetation within this region were subsequently analysed using 75 x 100 ft. plots (0.07 ha) with the long axis parallel to slope direction (see Figure 1 for plot distribution). Woody and herbaceous vegetation was evaluated at each site using tabular comparison of Braun-Blanquet (Mueller-Dombois and Ellenberg, 1974). Arboreal species 2.54 cm dbh or greater were evaluated using count-plot methods (cover %, density, and basal area) to produce an importance value (Curtis and McIntosh, 1951). Heights of all conifers between 5 cm dbh and 10 cm high were also measured. Numbers of seedlings less than 10 cm tall were evaluated for 20 ft. square (37 m^2) plots nested within the northwest and southeast corner of each 0.07 ha study site. Landscape factors (slope, aspect, and elevation) were recorded for each study site. Interrelations between importance values, frequency, percent cover, basal area and landscape factors were assessed using correlation and regression analysis (Sokal and Rohlf, 1969).

Conifer growth was evaluated using site index (Avery, 1967) based on height and age at dbh (1.4 m). Sapling growth rates were obtained for selected trees less than 5 cm dbh by cutting and aging stems at 2.25 ft (68.6 cm) intervals. This practice was not employed where seedling establishment was believed limiting to density of mature trees. Heights of trees over 3 m tall were determined with a slope corrected Spiegal Relaskop.

Age-diameter data were used to estimate age-size class distribution (survivorship curves) for conifers. Survivorship curves are log densities of each species per size class used to analyze successional trends (Jackson and Faller, 1973). Nomenclature follows Munz and Keck (1959) and Munz (1968).

RESULTS

Climate

Long term climatic records are not available for Onion Creek. U.S. Weather Bureau records from Norden (2,094 m elevation and 3.5 km due north of Onion Creek) indicate a winter-wet, summer-dry climate typical of the central Sierra Nevada above 6,000 ft. (U.S. D.A., 1955). Eighty-eight percent of total precipitation falls between November 1 and April 30 (95% as snow) when average maximum temperatures are below 10°C and average minima below freezing (Table 1). Ninety-one percent of annual precipitation arrives as snow. While hard freezes may occur during any month, temperatures below -25°C are apparently very rare. Mean maximum summer temperatures are in the 18 - 24°C range (Table 1), compared to 14.9°C for the three Sierra Nevada red fir zone stations listed in Oosting and Billings (1943).

Vegetation

Coniferous Forests

Sixty percent or 252 ha of the Onion Creek study area is coniferous forest. White fir forests (Society of American

Foresters cover type 211) (S.A.F., 1954) encompass 101 ha, mostly on gently sloping terrain below 2,000 m elevation about the southwestern third of the proposed natural area (Figure 2). Another 147 ha is red fir forest (S.A.F. cover type 207) located principally on north slopes above 2,000 m and in deep canyons subject to cold air drainage. South and west slopes between 2,000 and 2,250 m elevation form a complex mosaic of red and white fir forests. Abies concolor predominates on moderate south to west exposures on upland sites near rock scree. Abies magnifica is dominant upon gentle slopes and within sheltered canyons. Four hectares were also mapped as Jeffrey pine forest (cover type 247) at 2,070 m (6,800 ft) elevation on the ridge forming a western boundary of the proposed natural area (Figure 2).

White Fir Forest: Abies concolor is dominant at all forest sites examined below 1,950 m elevation and at sites above this elevation possessing moderate to steep south or west aspect. Mean and standard deviation for white fir importance values (IV) at these sites was 181 ± 51 (plots 8, 9, 10, 27, 24, 26, 11, 23; Figure 3). Basal area is the most variable phytosociological character at white fir sites averaging 91 ± 81 m^2/ha, followed by frequency (634 ± 521 stems/ha), and percent cover (58 ± 19%). Basal area possesses the greatest positive correlation with IV (r = 0.88) while frequency has the lowest correlation (r = 0.34). High variation in frequency results from large numbers of white fir stems occurring at sites which have undergone relatively recent increases in

Abies concolor dominance (plots 10, 24, 27; Figure 3). Reproduction within all white fir sites is dense, except for plot 24 where past reproduction has been so high the current overstory is too dense to permit survival of saplings.

Abies concolor basal area averages slightly over 50% of the total for the cover type, but variability is high, between 15.5 and 272 m^2/ha representing 18 to 92% of plot totals, respectively. The highest basal area is found at plot 24 where Abies concolor invaded an open Calocedrus stand approximately 100 years ago. Abies concolor basal area is less at sites where this tree grows with large specimens of mixed conifer forest species: Pinus lambertiana, P. Jeffreyi, and Calocedrus decurrens (e.g. plots 8-10, 27; Figure 3). Even at these sites, however, Abies concolor is proliferating at the expense of pines and incense cedar.

Pinus Jeffreyi usually occurs at low density throughout white fir forests: IV = 2.4 and 2.1 at plots 10 and 24, respectively (Table 3). Seedling or sapling Jeffrey pine are absent from forest sites. They do occur within open Pinus Jeffreyi stands on dry summits of ridges, but these sites are now being invaded by Abies concolor (plot 20; Table 2 and 3).

Large Pinus lambertiana are abundant within white fir forest on gentle topography below 2,000 m elevation, particularly within forest sites about dry meadows where this species may have been the principal dominant within a mixed conifer forest two or three centuries earlier. Today Pinus

lambertiana possesses an average frequency of 52 ± 43 stems/ha, 9 ± 5% cover, and basal area of 30 ± 19 m^2/ha. Importance Values are low, 33 ± 12 (Figure 3). Imtermediate size sugar pines are absent altogether and saplings, if present, are invariably of low vitality (plots 10, 26, 27; Table 2).

Calocedrus decurrens occurs throughout white fir forest but has highly variable phytosociological properties. It is quantitatively most importnat below 3,000 m elevation about margins of dry meadows (plots 8-10, 24; Table 3) and on south facing slopes (plot 27). Plot 26 is near the upper altitudinal limits of Calocedrus. Sapling and pole sized Calocedrus occur within fir forests, but are most vigorous along margins between forests and meadows where this species is rapidly increasing in abundance.

Abies magnifica is not abundant as mature trees below 1,950 m elevation, although seedlings and saplings may be very abundant. Importance Values are highly variable (IV = 57 ± 48). Average frequency, percent cover, and basal area for Abies magnifica is 192 ± 282 stems/ha, 19 ± 15% and 20 ± 19 m^2/ha, respectively (Figure 3). Despite high variability of Abies magnifica within white fir forests, there is a strong semi-logarithmic relationship between importance values of this species and proximity to the nearest signficant stands dominated by Abies magnifica
r = -0.95). Correlation between proximity to red fir stands and natural logarithm of Abies magnifica frequency, percent

cover, and basal area is r = -0.62, -0.80, and -0.93, respectively. This relationship is not unlike models for seed dispersal from a point source and suggests, but does not prove, white fir forests are almost uniformly available for establishment of red fir. Prior to the ascendence of both fir species, Pinus lambertiana, Calocedrus decurrens, and Abies concolor appear to have shared dominance more or less equally, forming semi-open stands within a mixed conifer forest on gentle topography below 1,950 m elevation.

Red Fir Forest: Abies magnifica is strongly dominant on north facing slopes above 2,100 m and along bottoms of canyons at lower elevation. Importance Values of Abies magnifica within the red fir type are consistently high (227 ± 23 for plots 13, 1, 16, 18, 22, 12, 2, 25, 15; Figure 3). Frequency is the most variable phytosociological character for Abies magnifica stands averaging 467 stems/ha but ranging from 101 to 1823 stems/ha (plots 15 and 12, respectively). Basal area for Abies magnifica is also variable (72 ± 25 m^2/ha), while percent cover is more stable (55 ± 14%). Correlation between Importance Values and phytosociological properties of Abies magnifica is poor; r = -0.18, -0.33, and -0.33, respectively between IV and frequency, cover, and basal area. The only significant correlation between a phytosociological character of Abies magnifica and a landscape factor is between basal area and slope (r = -0.77).

Principal associates with Abies magnifica in the red fir cover type are Pinus monticola and Abies concolor at high and

low elevation, respectively. White fir was recorded at 7 of 9 red fir sites where it accounted for 125 ± 96 stems/ha, and 18 ± 10% cover. Basal area averaged 19 m^2/ha but varied between 0.08 m^2/ha(plot 25) and 61 m^2/ha (plot 22). Average Importance Value is 62 ± 29. Variation in IV is most closely related to basal area (r = +0.71). Pinus monticola occurs in low density at 5 red fir sites, only two of which also possess Abies concolor (Table 2). Phytosociological characteristics of Pinus monticola are: frequency, 34 ± 19 stems/ha; percent cover, 7.2 ± 2.6%; basal area, 6.25 ± 5.5 m^2/ha; and IV, 29 ± 16. Importance Value is strongly correlated with basal area (r = +0.88) and frequency (r = +0.79). Lesser overall variability for Pinus monticola compared to Abies concolor within red fir forests occurs because the former tree is found at low density over much of the red fir cover type, while Abies concolor decreases progressively and is finally absent with increasing elevation on north facing slopes.

Pinus lambertiana and P. Jeffreyi also occur as single large trees within the red fir forest at low elevations and on south slopes (plots 12, 13, 16; Table 2). Tsuga mertensiana is an associate at high elevation red fir stands on north slopes (plot 15), and bases of deep canyons. At least one area on north facing topography at high elevation is dominated by Tsuga (plot 14).

Subordinate species commonly associated with Onion Creek fir forests are Asclepias cordifolia, Chimaphila umbellata,

Corallorhiza maculata, Hieracium albiflorum, Kelloggia galioides, Osmorhiza chilensis, Phacelia hydrophylloides, Pedicularis semibarbata, Pterospora andromedea, Pyrola picta, Pyrola picta ssp. dentata, Ribes Roezlii, and Symphoricarpos rotundifolius (Table 2). Additional species largely confined to lower elevation within white fir forest (areas previously believed to be high elevation mixed conifer forest) are Adenocaulon bicolor, Goodyera oblongifolia, Smilacina stellata, and Thalictrum Fendleri. Arabis platysperma and Chrysopsis Breweri occur most frequently within red fir forests (Table 2). Shrub and herb stratum taxa found within fir forests, but widespread in other vegetation types are Arabis glabra, Bromus marginatus, Collinsia parviflora, Galium Aparine, Gayophytum ramosissimum, Monardella odoratissima, Phacelia racemosa, Rhamnus californica ssp. occidentalis, and Sidalcea malvaeflora. Quercus vaccinifolia occurs as an occasional shrub within fir forests, but nowhere attains the dense cover characteristic of steep south exposures.

Dry meadows comprise 14 ha and are characterized by abundance of Lotus nevadensis, Madia exigua, Poa sp., Trifolium sp., Verbascum Thapsus, Cirsium sp., and others (plots 6, 19, 21; Table 2). Rumex paucifolius, Sitanion Hystrix, and Eriogonum nudum are also abundant, but are shared with other dry exposed sites (plots 3-6; Table 2). Encroachment by Abies concolor, Calocedrus decurrens, and, to a lesser extent Pinus Jeffreyi, has significantly reduced dry meadow habitats below 2,012 m (6,600 ft). Dry meadows above 2,012 m elevation

are being invaded by Abies concolor and A. magnifica, but the rate appears much slower. Abundance of young vigorously growing conifers within most remaining dry meadow sites indicate this trend is continuing.

Non Commercial Cover Types

Non commercial cover types were mapped over 162 hectares or 39% of the proposed natural area. The large majority of this area is rock scree, cliff, and talus slopes which form a topographic timber line above approximately 2,200 m (7,200 ft) elevation (Figure 2). The salient feature of rock scree is high erodibility due to a combination of steep rocky slopes, high snowfall, and elevation below 2,500 m which renders them susceptible to rare, warm winter storms which can melt a snowpack within 24 hours.

Less steep and rugged micro-habitats within this rock scree occasionally support snow and wind trained specimens of Juniperus occidentalis ssp. australis and Pinus Jeffreyi. Herb stratum cover is sparse, seldom exceeding 50% and usually only a few percent, and includes both xeric subalpine taxa (Eriogonum umbellatum ssp. polyanthum, E. Lobbii), widespread great basin species (Artemisia tridentata), and xeric montane species (Arctostaphylos nevadensis, Ceanothus cordulatus, C. prostratus, Collinsia parviflora, Gayophytum ramosissimum, Helianthella californica, Monardella odoratissima, Phlox diffusa, Sitanion Hystrix, Wyethia mollis and others) (See Plot 3; Table 2).

Quercus vaccinifolia (huckleberry oak) forms dense scrub cover over 32 ha of the natural area, nearly all of which is on steep south exposure. Quercus vaccinifolia is dominant but other montane chaparral, dry meadow, and scree species are also present: Allium campanulatum, Arctostaphylos nevadensis, A. patula, Carex sp., Calochortus Leichtlinii, Ceanothus cordulatus, C. prostratus, Poa sp., Melica sp., Pellaea Bridgesii, Penstemon speciosus, Rumex paucifolius, Sitanion Hystrix, Stipa coronata, Wyethia mollis as well as widespread species (plot 5; Table 2). Moderate exposures within huckleberry oak scrub are being invaded by firs: Abies concolor and A. magnifica, and to a lesser extent, by Calocedrus decurrens and Pinus Jeffreyi. Ecotones between fir forests and huckleberry oak scrub are almost everywhere characterized by "invasion fronts" of dense sapling and pole sized conifers, particularly Abies concolor. Between 6,400 and 6,800 ft. elevation on the south facing ridge forming the western boundary of the natural area, this "invasion front" has become large enough to map (see Ac-Qv type in Figure 2). Fir thickets in old huckleberry oak scrub are almost always on dry south exposures which are capable of carrying crown fire.

Non commercial forest types occur on slightly less than 10 hectares. Alnus tenuifolia thickets are most prevalent (9.3 ha) and are concentrated about seepage areas and along lower slopes of steep canyons where avalanches prevent intrusion of taller coniferous forests (Figure 2). Shrub

stratum cover is usually 75% or more with Alnus tenuifolia dominant. Scattered specimens of Acer glabrum var. Torreyi and Salix Scouleriana may also be present. Understory vegetation is a floristically rich assemblage of mesophytic species. Grasses are particularly conspicuous in wet open seepage areas between patches of Alnus (plot 7; Table 2). Acer glabrum often attains dominance in moist soil about the outer margins of Alnus thickets (approximately 0.3 ha in Figure 2). Like Alnus stands, Acer glabrum thickets are mesophytic and floristically rich. However, moisture appears to have little to do with the distribution of Acer glabrum as small isolated clusters of this shrub occur throughout the fir forest (plots 9, 13, 14, 22, 23, 25) and in open rocky scree or scrub areas (plots 3-4; Table 2).

Salix Scouleriana occurs as individual stems or stem clusters throughout the coniferous forest and adjacent vegetation. Observation suggests nearly all Nuttall willows are located near temporary springs or other regions with shallow water tables. Populus trichocarpa occurs along Onion Creek at the extreme western edge of the natural area. The trees occupy an area too small to map and are an extension of a larger stand growing in the abandoned Onion Creek campground area immediately to the west. A cluster of Populus tremuloides clones also occurs over 0.1 ha along the ecotone between dry meadow and Alnus tenuifolia cover types (Pt in Figure 2).

Growth

Growth of Abies magnifica and A. concolor within closed forest stands is essentially equal and, for all practical purposes, linear between 5 and 30 years after establishment (Figure 4). Exponential growth may begin immediately for firs growing on open sites (plot 23; Figure 5). Exponential growth of fir saplings growing under forest cover is usually apparent 30 years after establishment (Figure 5 and 6).

Sapling Abies magnifica and A. concolor attained breast height (1.4 m) in 63 ± 19 years (n=28) and 49 ± 20 years (n=18), respectively. For both species growth was negatively related to overstory cover. Trees growing in open sites within fir forests probably attain breast height between 15 and 30 years after establishment (plot 23, Figure 5). Abies developing upon level to moderate slope where overstory cover does not exceed 50% continue exponential growth after attaining breast height (plots 10, 16, 18, 26; Figures 5 and 6). (See Table 2 for percent tree stratum cover of plots). If terrain is steep and at high elevation on north aspect (plot 13) or possesses dense overstory cover (plot 12), a point of inflection occurs at approximately breast height and trees enter either a linear or decreasing growth phase. For trees growing under dense (75% or greater) overstory growth rates may become very low although mortality seldom occurs unless the sapling leader has been destroyed. Growth reduction of Abies developing upon steep north aspect occurs when heavy snows repeatedly lodge saplings. Exponential growth resumes if the tree can

develop a trunk sufficiently strong to resist lodging, and/or grow above the level of the snow pack. Abies magnifica saplings develop sturdy trunks capable of resisting lodging. Sapling Abies concolor, however, are readily lodged by accumulated snow at higher elevation on north slopes. Leaders of lodged Abies concolor continue to elongate but gain little actual height above the forest floor. White firs which are repeatedly lodged are susceptible to physical damage. Fungal attacks upon needles are also frequent, resulting in rare establishment of this species on steep north slopes above 2,100 m elevation (e.g. plot 25).

Fastest growth of Abies magnifica and Abies concolor occurs on gentle south to west aspects. Increases in Abies regeneration during the past 50 to 100 years have resulted in dense overstory and few etiolated saplings with very low growth rates. Firs invading a nearby dry meadow indicate these trees required 15 to 30 years at most to reach breast height and will grow to about 34 m tall after 100 years age at breast height (plots 9, 18, 24; Table 3, Figure 7). Growth of both fir species within the forest is slightly less. Trees reach breast height in approximately 50 years (40 ± 18 years, $n = 7$ for Abies concolor and 60 ± 18 years, $n = 14$ for A. magnifica) and are approximately 10 m tall at 40 years age at breast height (plots 1, 8, 10, 15, 20, 22, 23, 25, 26, 27; Table 3, Figure 7). During the next 40 years, they will grow rapidly (approximately 0.3 m/yr). This growth rate slows to

0.18 m/yr between 80 and 120 years age at breast height, to 0.11 m/yr for the 120 and 160 year interval, and 0.05 m/yr between 160 and 200 years at breast height.

Abies magnifica growth is slightly less for steep north aspects (plot 13) or exposed areas along ridges (plots 2, 16), where trees attain breast height after slightly more than 50 years (Table 3) and reach 18 m tall after another 100 years (Figure 7). Least red fir growth encountered in this study was on a very steep north aspect within a Tsuga mertensiana grove. Here approximately 70 years is required to reach breast height and trees are less than 10 m tall a century later (plot 14; Table 3, Figure 7). Least Abies concolor growth was observed on old glacial moraines with south aspect where trees grow to approximately 15 m height when they are 100 years old at breast height (plot 11).

At most sites within the white fir cover type, Abies concolor reach 36 cm diameter at breast height (dbh) approximately 100 years after leaders first attained breast height (1.4 m). Diameter growth increases during the second 100 years of growth, averaging 0.60 cm/yr (Figure 8). However, estimated growth declines to an average of 0.37 cm/yr between 200 and 300 years age at breast height, and to 0.26 cm/yr after 300 years. Abies concolor developing on excellent sites (those with gentle topography and porous soils) average 0.77 cm/yr diameter growth over the first 100 years after attaining breast height(Figure 8), and probably grow 0.52 cm/yr between 100 and 200 years age at breast height.

Diameter growth of Abies magnifica is less than for A. concolor, averaging 0.34 cm/yr over the first 100 years after these trees reach breast height, and increasing to 0.53 cm/yr between 100 and 200 years age at breast height (Figure 8). Estimates of subsequent growth are 0.45 cm/yr between 200 and 300 years, and 0.23 cm/yr for trees over 300 years old at breast height. Abies magnifica established on open sites grow faster during the first 100 years after attaining breast height (0.40 cm/yr), but subsequent growth rates do not appear to be significantly greater than for most other red fir sites (Figure 8).

Age-diameter data for trees and saplings (Figure 8) and ages of saplings at breast height (pages 13-14) provide a basis for approximating the sizes of 50 year age classes used in the following evaluation of stand structure (Table 4).

Structure

Structure of white fir and ref fir forests within the proposed natural area is evaluated separately to facilitate understanding possible changes which have occurred over time between these two adjacent plant communities. White fir forest is defined as stands where Importance Value (IV) of Abies concolor exceeds 100 and is also greater than the IV for A. magnifica (see plots 8-23; Figure 3). Plots belonging to red fir forest, on the other hand, possess A. magnifica IV's exceeding 200 and have IV's for A. concolor less than 100 (plots 13-14; Figure 3).

Within white fir forest density of A. concolor per 50-year age class illustrate steep log-linear decline with increasing age (Figure 9). The only exceptions are age-class 8 trees (350 to 400 years old) which are over-represented. Increase in abundance of A. concolor appear to have been greatest between age class 6 and 5, spanning the period 1675-1775 and again between age classes 3 and 2 (1825 to 1925). Abies magnifica within white fir forest illustrate the same structural trends as does A. concolor prior to 1725 (age class 6), but amplitude of variation in density per age class is less than for white fir. Between 1725 and 1825 A. magnifica establishment probably did not increase enough to replace specimens belonging to older age classes while successful establishment of A. concolor began to increase sharply. After about 1825 establishment of A. magnifica also increases sharply (Figure 9). As a result of these trends much of what we recognize today as white fir forest was actually dominated by red fir up to 150 years ago. Since 1825, 71 ± 8% of firs established in forest currently described as white fir forest have been A. concolor. This compares to only 34 ± 4% A. concolor for the four age classes prior to 1825.

Establishment of pines within white fir forest has been gap-phase. Pinus lambertiana illustrates peak reproduction before 1525 (age class 9), between 1625 and 1675 (age class 7), and from 1875 to 1925 (age class 2). A significant gap in sugar pine reproduction and/or establishment spans the period 1675 through 1825 (age classes 6 through 4). Pinus lambertiana belonging to age class 1 (1925 to 1975) are mostly suppressed

saplings which are unlikely to contribute to larger size classes. For Calocedrus decurrens peak establishment periods also occurred prior to 1525 and between 1625 and 1675. More recent peaks in establishment, however, have been different than for sugar pine, e.g. 1775 to 1825 and 1875 to the present. Little or no successful establishment of Calocedrus appears to have taken place between 1675 and 1775 (Table 5). Most old Pinus jeffreyi date from the period 1625 to 1675. Significant Jeffrey pine establishment has also occurred between 1825 and the present (Table 5).

Examination of specific plots within white fir forest reveal strucutral trends in space as well as time. Forests of dense young A. concolor within which are found widely spaced "relict" Calocedrus decurrens were dry meadows where incense cedar possessed aspect dominance 100 years ago (plot 24; Table 6). Calocedrus decurrens, Pinus lambertiana, Abies concolor, and, locally, Pinus jeffreyi are present on gently sloping topography about dry meadows (plots 8 and 9) and on lower slopes of south aspects (plot 27; Table 6). Prior to an increase in A. concolor establishment beginning about 1750, these sites were apparently semi-open mixed conifer forest. Abies magnifica was either absent from these stands prior to 1825, or specimens present were old and have subsequently fallen and decomposed.

White fir study sites located further into the forest from dry meadows (plots 10, 26; Table 6) possess large specimens of all conifers found within upper elevation

conifer forest at Onion Creek: Pinus lambertiana, P. jeffreyi, Calocedrus decurrens, Abies concolor, and A. magnifica.

Density of Abies magnifica per size class within red fir forest declines according to a negative log-linear relationship indicating over-all stability of this species for at least the past 400 years. Modest exceptions are size class 6 (representi specimens between 1675 and 1725) which has above-normal representation, and size classes 4 and 5 (1825-1725) which are slightly under-represented. Reproduction and/or survival durin the past 50 years has also been high (Figure 10).

Examination of A. magnifica at individual 0.07 ha study sites reveals local gap-phase stand structure for this regionally stable species. Mature red fir forests are open stands of large trees between 200 and 500 years old which usual have large numbers of seedlings and small saplings (plot 15; Table 6). When a few overstory trees are removed, usually through wind-throw, suppressed saplings are released in opening (plot 2) and grow vigorously forming dense cover in areas with open overstory (plot 22; Table 6). If wind throw is extensive or A. magnifica invades a previously open site, the entire forest may consist of young, middle-age (plot12), or maturing red firs (plot 23; Table 6).

Pinus monticola is found in low numbers throughout Onion Creek red fir forest. Like Abies magnifica density of P. monticola per size class forms a predominantly negative log-linear relationship. Exceptions are size classes 3 (1825-1875) and 4 (1775-1825) which are, respectively, over and under represented (Figure 10).

In contrast to red fir and western white pine, log densities per size class of associated species which have upper or lower elevational limits within red fir forest are strongly gap-phase. Tsuga mertensiana occurs within red fir forest on steep north facing slopes above 2,100 m and on north facing toes of slopes within deep canyons. Peaks in mountain hemlock reproduction or survival have occurred in size classes 7 (1625-1675), size class 4 (1775-1825), and during the past 100 years. Little or no specimens occur representing reproduction which would have occurred between 1675 and 1775 (Table 5).

While a few very old A. concolor exist within red fir forest (one specimen at plot 18 measures 1.84 m dbh, 45 m tall, and is estimated to be 500 years old) little if any successful establishment occurred between 300 and 400 years ago (1575-1675). Successful establishment of A. concolor resumed between 1675 and 1775 (size classes 5 and 6). After a slight decline in establishment between 1775 and 1825, white fir reproduction increased sharply up to and including the present (Figure 10). Until 1825 to 1875 conditions within red fir forests which favored Abies magnifica were detrimental to A. concolor and vice versa.

Recent increases in numbers of Abies magnifica or Pinus monticola within red fir forest are not large enough to result in major changes in composition of this climax forest cover type over coming centuries. Lower elevation sites which have experienced an upsurge in Abies concolor, will combine with an A. magnifica increase within upper elevation white fir

forest, to produce a broadening of the mixed fir forest forming an ecotone between true red fir and mixed conifer forest cover types.

Potential Solar Beam Irradiation and Distribution of Cover Types

Potential solar beam irradiation (PSBR) is a theoretical parameter reflecting the intensity of solar irradiation a surface would receive if factors which vary from day to day (clouds, smog, dust, atmospheric moisture) are ommitted. Although PSBR usually differs appreciably from actual irradiati at a given site, it provides a meaningful method for comparing energy flux of different landscapes (Frank and Lee, 1966). Potential solar beam irradiation is used here to compare "typical" slope-aspect conditions (derived from Figure 2) for the various forest, scrub, and meadow cover types occurring within the Onion Creek study area (Table 7).

Potential solar beam irradiation, particularly winter PSBR, is strongly correlated with the distributions of several vegetation cover types within the Onion Creek region. Abies magnifica - Pinus monticola forests receive least PSBR (under 200 x 10^3 ly/yr) with late fall (Nov. 5 - Feb. 7) values under 250 ly/day (Table 7). Similarly, fall through spring PSBR is low within Tsuga mertensiana - Abies magnifica forest. While annual PSBR for Abies magnifica - Pinus monticola forest is under 200 x 10^3 ly/yr, Abies magnifica - A. concolor stands usually exceed 250 x 10^3 ly/yr with December 22 PSBR ranging between 200 and 600 ly/day (Table 7). Abies concolor is not

dominant within mixed white fir - red fir stands at Onion Creek unless winter (Dec. 22) PSBR exceeds 500 ly/day. Between 1,860 and 2,100 m elevation Abies concolor occurs with Pinus Jeffreyi on west slopes where December 22 PSBR approaches 300 ly/day, but spring and fall potential irradiation is high (between 500 and 1100 ly/day) (Table 7). At Onion Creek Pinus lambertiana and Calocedrus decurrens do not appear to enter Abies concolor forest until winter PSBR exceeds about 400 ly/day. Open Pinus Jeffreyi forest which has been invaded by Abies concolor during the past half century is characterized by relatively high fall and spring PSBR (840-950 ly/day) and very high winter PSBR (above 550 ly/day).

Two types of Quercus vaccinifolia scrub occur: thickets on south-southwest slopes with December 22 PSBR exceeding 600 ly/day and annual PSBR greater than 300 x 10^3 ly, and steep west-northwest or less steep south exposures where December 22 PSBR is less than 500 ly/day and annual PSBR is under 300 x 10^3 ly. The former sites nearly always appear as pure stands of Quercus vaccinifolia although the latter have been intensively encroached upon by conifers (particularly Abies concolor) during the past 100 years. Rock scree terrain is usually steep and with south and west aspect. South aspects receive high spring PSBR. West slopes have less PSBR at this time favoring prolonged cover by snow (Table 7).

DISCUSSION

Environmental factors believed responsible for separating major vegetation cover types within the Onion Creek study area are summarized in Figure 10. Steep topography along the suture zone between Miocene volcanic pyroclastic rock and the more recent Pliocene volcanic pyroclastic deposit (Burnett and Jennings, 1962), respectively, form an approximate boundary between high elevation fir forest and the cliff and talus topography characteristic of rock scree. Extensive areas of unweathered parent material and extreme erosiveness of weathering products which are formed within the rock scree create a topographic tree line. During infrequent periods of heavy winter rains, a year's snow pack may melt from these slopes (which are mostly between 7,200 and 8,000 ft elevation) in a matter of hours. Sudden melting of the rock scree snow pack last occurred in December 1964 sending torrents of rock and debris into the tributaries of Onion Creek, destroying adjacent forest cover types. Transition from rock scree to scrub or forest cover types is occurring, but the time scale is that of primary succession.

Quercus vaccinifolia occurs in dense nearly pure stands on steep (60% or greater) south to west facing slopes which are often contingent upon the rock scree cover type. Huckleberry oak scrub also occurs on less steep slopes. Here the cover type is being colonized by conifers, particularly Abies. Very high fall through spring PSBR of steep south exposures extends the snow free period and apparently prevents establishment of

Abies, probably through critically low summer and fall seedling water potentials. Quercus vaccinifolia is also well adapted to crown-type fires which would be the most likely type of fire to burn on steep to moderate sloping south or west aspects. Conifers can become established within Quercus vaccinifolia scrub between fires on moderate south aspects and steep to moderate west aspects. In some areas conifer establishment has been sufficiently great to produce a definitive "invasion front" of fir saplings and small trees along ecotones between Quercus vaccinifolia scrub and fir forests. However, these trees will not survive the next fire.

Only 4 ha of gentle (10-30%) slopes of south facing ridge crests within the Onion Creek study area are vegetated by open stands of Pinus Jeffreyi. These stands are usually adjacent to steeper slopes characterized by Quercus vaccinifolia scrub, and may form ecotones with this scrub when shallow rocky soils prevent formation of dense scrub cover which is capable of carrying a hot fire. Open Pinus Jeffreyi stands are currently being encroached by Abies concolor and A. magnifica. Suppression of fires is probably responsible for a large measure of fir encroachment into Pinus Jeffreyi forest, but, as will be discussed, climatic factors are also implicated.

The remaining 98% of Onion Creek conifer forests are dominated by Abies of which A. magnifica and A. concolor are, respectively, dominant over 147 and 101 hectares. Red fir forest is confined to north facing slopes above 2,000 m elevation and to deep or otherwise sheltered canyons which experience cold air drainage. Mode of restriction of Abies magnifica to these sites is probably drought stress which is directly

related to the length of the snow free period. Within red fir forest Abies magnifica is clearly dominant (Importance Values average 227 for 9 sites examined). Associated trees are Pinus monticola, P. Jeffreyi, Abies concolor, and Tsuga mertensiana. Pinus monticola occurs throughout red fir forest at low density while the latter three species possess upper or lower elevational limits within this cover type. Relatively nonflammable litter and deep shade resulting from the Abies magnifica overstory exclude Pinus Jeffreyi from all but semi-open sites which usually possess south aspect components. Additionally, heavy snow accumulation upon north aspects appears to selectively lodge white fir thereby excluding this tree from higher elevation sites. Higher fall through spring irradiation lessens the extent and duration of the snow pack on south and west exposures, thereby reducing the probability deep snow cover will lodge sapling white firs. Results are mixed white and red fir stands on these aspects extending up to the rock scree. Tsuga mertensiana occurs at the coldest red fir sites, those on steep north aspects above 2,200 m or along bottoms of deep canyons subject to extended cover by snow. Single large specimens of Pinus lambertiana occur within low elevation red fir forest on exposed lateral ridges where most Abies magnifica are young (150 years old or less), suggesting an invasion of red fir into previously open sites.

White fir forest occurs on gently sloping terrain below 1,950 m and on exposed south or west aspects up to 2,250 m elevation where conifer forests usually form sharp ecotones with ro scree. Importance Values for Abies concolor average 183 for 8 sites examined, and ranged from nearly pure white fir stands

to sites where white fir grows with large specimens of Pinus lambertiana, P. Jeffreyi, Calocedrus decurrens, and/or Abies magnifica. Pines and incense cedar are largely confined to substrate left from old glacial moraines (Burnett and Jennings, 1962), although it is not known if there is any ecological significance to this correlation. Abies magnifica occurs at nearly all white fir sites studied but there is a strong negative exponential correlation between distance from existing stands dominated by red fir and current frequency of this tree, indicating recent "invasion" of white fir forests by red fir.

Structure of Onion Creek fir forests reveal characteristics potentially significant to the management of this region as a natural area. Numbers of Abies concolor within white fir forest have increased steadily since 300 to 350 years ago. Increases in Abies concolor coincide with increasing warmth which was augmented by above normal precipitation 50 to 100 years ago (LaMarche, 1974). A moderately cool but exceptionally moist period in the early 15th Century may also coincide with greater than expected numbers of Abies concolor.

Establishment of Abies magnifica within white fir forest appears to be enhanced by cold moist climate and hindered by relative drought. Moist conditions about 1625 and 1750, respectively, are associated with higher than expected numbers of 350 to 400 year old and 200 to 250 year old A. magnifica. Periods of drought between 1675 and 1725 and again between 1775 and about 1860 (LaMarche, 1974) are associated with lower than expected representation of A. magnifica. Climate has been warming from about 1625 to the present, but it was not until precipitation increased in the late 19th and early 20th Centuries

(LaMarche, 1974), that successful establishment of A. magnifica within white fir forests increased sharply.

Successful establishment of Pinus lambertiana within white fir forest is positively related to periods of very moist climate, e.g. 1575-1625 and during the early 20th Century (LaMarche, 1974). Few if any sugar pine became established between 1675 and 1875 when climate was predominantly dry. Peak establishment of Calocedrus decurrens, however, has occurred during relatively dry periods: 1775 to 1825 and 1925 to the present. While too few Pinus Jeffreyi were sampled to provide a definitive assessment of structure, age-density relationships suggest successful establishment occurs during periods of drought and/or warmth, e.g. 1625-1675 and 1825 to the present, particularly since 1925.

Variations in density for different age classes of conifers associated with Abies magnifica within red fir forest are also closely correlated with climatic events likely to induce the structural changes observed. Abies concolor possesses an upper elevational limit within red fir forest and has two definable gaps in its age-density relationship; one extends from about 1575 to 1675 (a period of extreme cold-moist climate in the vicinity of the Sierra Nevada), while the second gap occurs between 1725 and 1775 (a period also characterized by cold-moist climate) (LaMarche, 1974). Lodging of sapling Abies concolor (size classes 1 and 2) has been implicated in defining the current upper elevational limits of this tree on north slopes. Destruction of these same two size classes could have resulted

from unusually deep or prolonged snow cover generated by abnormally cold-moist climate in the early 17th Century, and would appear as a gap in size classes 7 and 8 today. Abundant establishment of Abies concolor appears positively related to normal and especially above normal temperature conditions. Modest increases in white fir establishment and/or survival occurred prior to 1575 and again between 1775 and 1825. Both periods were characterized by temperature and moisture conditions near the mean for the period 800 to 1960 A.D. (LaMarche, 1974). Warming of regional climate starting about 1850 has been correlated with sharp increases in abundance of Abies concolor within Onion Creek red fir forests. The ascendence of Abies concolor has also been progressive, starting at lower elevations and extending upward.

Definable increases in successful establishment of Pinus monticola date back to the period 1725 to 1775 and, again, between 1925 and the present - periods respectively characterized as near normal and warm-dry (LaMarche, 1974). Increased establishment of Pinus monticola within red fir forest during periods of relative drought appear reasonable considering western white pine is more prevalent, even dominant, on slopes of Babbit Peak (45 km north of Onion Creek) which are both aspectionally and elevationally suitable for Abies magnifica except for the dry climate (Talley, 1977). Absence of Pinus monticola belonging to age classes 8 and 9 (350 years old and greater) could have resulted from damage inflicted upon young pines during heavy snows which probably accompanied cold-moist

conditions during the early 17th Century. Peaks in successful establishment of Tsuga mertensiana have occurred during abnormally cold-moist weather about 1620 and 1770, although age class 1 (1925-1975) was warm-dry and is also well represented.

Climatic changes apparentaly have not resulted in significant structural variability of Abies magnifica within red fir forests, attesting to the over-all suitability of north slope habitats at Onion Creek for this species. As climate varies from cold-dry to cold-moist and warm-moist to warm-dry, relatively more or less reproduction and establishment of Abies magnifica may occur. However, there are always more trees established than can ever survive into the overstory (size class 3 and above) so the forest maintains relative stability despite environmental variability.

Uniformity between climatic change and forest trends within Onion Creek, white fir forests provide little support for theories that high rates of fir establishment are largely a result of suppression of natural and man-caused fires (Biswell, 1967). At the same time we cannot discount Wagener's (1961) assessment of the early fire records within Sierra Nevada mixed conifer forest, or anthropological records of burning habits for Sierra Maidu Indians whose territory encompassed the Onion Creek study area (Kroeber, 1925). The 8 to 10 year interval between surface fires derived by Wagener for mixed conifer forests may have been closer to 20 to 30 years at Onion Creek, as this site is at the upper elevational limit of the mixed conifer type in the central Sierra Nevada, and probably

at the extreme upper elevational limits of the Maidu Indian fire management practice. The basis for this conjecture is absence of known Maidu settlements near the Onion Creek study area and knowledge these Indians rarely ventured more than 30 km from their native villages (Kroeber, 1925). Furthermore, significant areas of Onion Creek fir-pine forests were dominated by Abies magnifica prior to about 1725 and this cover type does not burn readily (Kilgore, 1971).

Actual fire frequencies probably varied significantly over the life spans of individual trees due to climatic fluctuations. The extent of congruence between probable climate and fluctuations in tree reproduction and/or survival is too great to ascribe to chance alone. Climatic change has been sufficient to at least partially explain extensive changes which have recently occurred in Onion Creek fir forests. Warm-moist conditions occurring about the turn of the century and current warm-dry climate represent extreme departures from the predominantly cold climate which prevailed since the beginning of the fourteenth century (La Marche, 1974). The last warm-moist period occurred during the eleventh and twelfth centuries and was followed by warm-dry conditions which lasted through the thirteenth century A.D. A reasonable hypothesis is that changing climate and suppression of natural and Indian fires have been equally responsible for bringing about structural changes in Onion Creek fir-pine forests. Structural changes within the red fir forests, on the other hand, are believed to derive mainly from climatic variability. Dates of fires

and widths of individual tree rings taken from large fir and pine stumps on cut-over lands adjacent to the proposed Onion Creek Research Natural Area would be of considerable value in defining this hypothesis.

Dry meadows below 2,000 m elevation are being invaded by conifers while those at higher elevation appear relatively stable. Limited versus widespread invasion of dry meadows, respectively, above and below 2,000 m elevation suggests other than climatic causes, and underscores a potential difference in fire frequencies with lower and upper elevation sites at Onion Creek. An hypothesis worthy of further study is that high elevation meadows possess fine textured soils which possess too little available moisture in summer and fall to permit conifer establishment. Significant areas of lower elevation meadows are also likely to be unsuitable for conifer establishment, but more frequent fires (probably started by Indians) permitted meadow establishment on more coarse textured soils adjacent to areas where meadows had an edaphic basis. With the current era of fire suppression, marginal meadow land is being reclaimed by forests - a change which may have been accelerated by warm-moist climate earlier in this century (LaMarche, 1974).

Significant numbers of herbaceous species appear to be characteristic of several Onion Creek vegetation cover types: Alnus tenuifolia thickets, dry meadows, and rock scree. Quercus vaccinifolia scrub, on the other hand, may be typified only by the dominance of this one species. Only 18 subordinate species are believed to be characteristic of Onion Creek conifer

forests, none of which appear to be confined to either the red fir or white fir cover types, although Arabis platysperma and Chrysopsis breweri are more abundant within the red fir type (see page 9 for list of characteristic species). At least three herbaceous species are found within fir-pine forests below 1,950 m which do not extend into the true fir forests: Adenocaulon bicolor, Galium aparine, and Goodyera oblongifolia. If wide ranging species found in true fir forests and adjacent non-forest cover types are added to the list of characteristic species there is close agreement between herbaceous composition of Onion Creek forests and the red fir association as studied by Oosting and Billings (1943).

Oosting and Billings further defined two herbaceous unions within the red fir forest. One union, the Pyrola-Corallorhiza union, consists of saprophytic or low evergreen herbs found in dense shade and deep coniferous litter: Pyrola picta, Corallorhiza maculata, Pterospora andromedia, Chimaphila umbellata, and others. A second Chrysopsis-Monardella union, consists of species characteristic of semi-open fir stands where mineral soil is near the surface: Chrysopsis breweri, Gayophytum ramosissimum, Pedicularis semibarbata, and Phacelia hydrophylloides. At Onion Creek these unions appear valid for red fir, white fir, and fir-pine forests. Study sites possessing three or four members from the Pyrola-Corallorhiza union (Plots 8-11, 13, 15, and 26) have but one or two species belonging to the Chrysopsis-Monardella union, and stands with three or more Chrysopsis-Monardella species (Plots 1, 2, 16,

18, and 20) similarly have only one or two representatives from the Pyrola-Corallorhiza union. Sites with very dense shade (Plots 12 and 24) have only Pyrola picta and Chimaphila umbellata. High elevation fir forests with south exposure (Plot 22) appear to possess representation by both unions.

Relative mutual exclusion of these two herbaceous unions is also confirmed for red fir forests about Bourland Meadow in the central Sierra Nevada (see Table 1 in Talley, 1976), although the specificity of these two unions becomes indistinct at Babbitt Peak on the northeastern montane xeric border of the Sierra Nevada (see Table 1 in Talley, 1977). At Babbitt Peak Pterospora andromedea (a "deep shade" species) becomes specific for open Washoe pine forests, while Chrysopsis breweri does not occur within conifer forests, but is found within mountain mahogany woodland! Only Pyrola picta ssp. dentata and Kelloggia galioides appear to be both confined to coniferous forests and mutually exclusive.

RECOMMENDATIONS

The proposed Onion Creek Research Natural Area possesses excellent examples of unlogged high elevation fir-pine, mixed fir, and red fir forests. Significant examples of dry meadow, huckleberry oak scrub, and rock scree are also contained within the proposed natural area. Cover types present but poorly represented include open Jefrey pine forest, mountain hemlock forest, mountain alder thickets and a very small aspen grove. The ecological integrity of the Onion Creek watershed makes this region particularly advantageous from the standpoint of creating a natural area.

However, important changes have taken place within Onion Creek forests and meadows over the past century which must be understood in greater detail before this area can be managed on a scientific basis. Expansion of conifer forests into dry meadows below 2,000 m has or may soon effect about 10% of the natural area. Causes of this change should not be left to speculation. The hypothesis put forward in the discussion should be refined by comparing areal photographs of differing ages. However, the mechanisms of conifer invasion into dry meadows will probably remain obscure until both "high" and "low" elevation meadows and adjacent forests are examined in detail respecting soil texture, soil water potential (matrix potential), ages of invading saplings, sapling water potentials, climate, and dates of fires.

Additional study will also be required to distinguish the relative roles of fire and climate upon structure of Onion Creek forests. Data needed include an accurate age-diameter relationship for each conifer species throughout the past 400 years, dates of fires (taken from fire scars on trees), and ring width-climate correlations (taken from logged areas adjacent to the natural area). The latter data would permit derivation of local climate-growth relationships which could be used to further evaluate stand structure. Ideally these data could provide a quantitative fire and climatic history for this region over the past four centuries. Pure or nearly pure red fir forests can be recognized as a true climax that will require no management for its perpetuation.

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Table 1. Climatic Summary for Norden, California Approximately 3.5 Km Due North of Onion Creek Candidate Research Natural Area.

Part A. Temperature (1905-1929)

Month	Ave. Maximum (°C)	Maximum (°C)	Ave. Minimum (°C)	Minimum (°C)	Average (°C)
January	1.8	23.9	-6.7	-23.3	-2.3
February	2.6	16.1	-5.4	-22.2	-1.5
March	3.7	18.3	-4.5	-16.7	-0.3
April	6.9	21.7	-2.8	-18.9	2.1
May	12.3	29.4	0.7	-12.2	6.3
June	17.6	29.4	4.0	-8.9	11.7
July	23.2	32.2	6.6	-2.8	15.9
August	22.7	32.2	5.9	-6.1	15.4
September	18.8	31.1	4.0	-6.7	11.9
October	12.6	32.2	0.3	-12.2	6.9
November	7.5	24.4	-3.4	-18.9	2.2
December	2.9	17.8	-6.1	-20.5	-1.1
Year	11.1		-0.6		

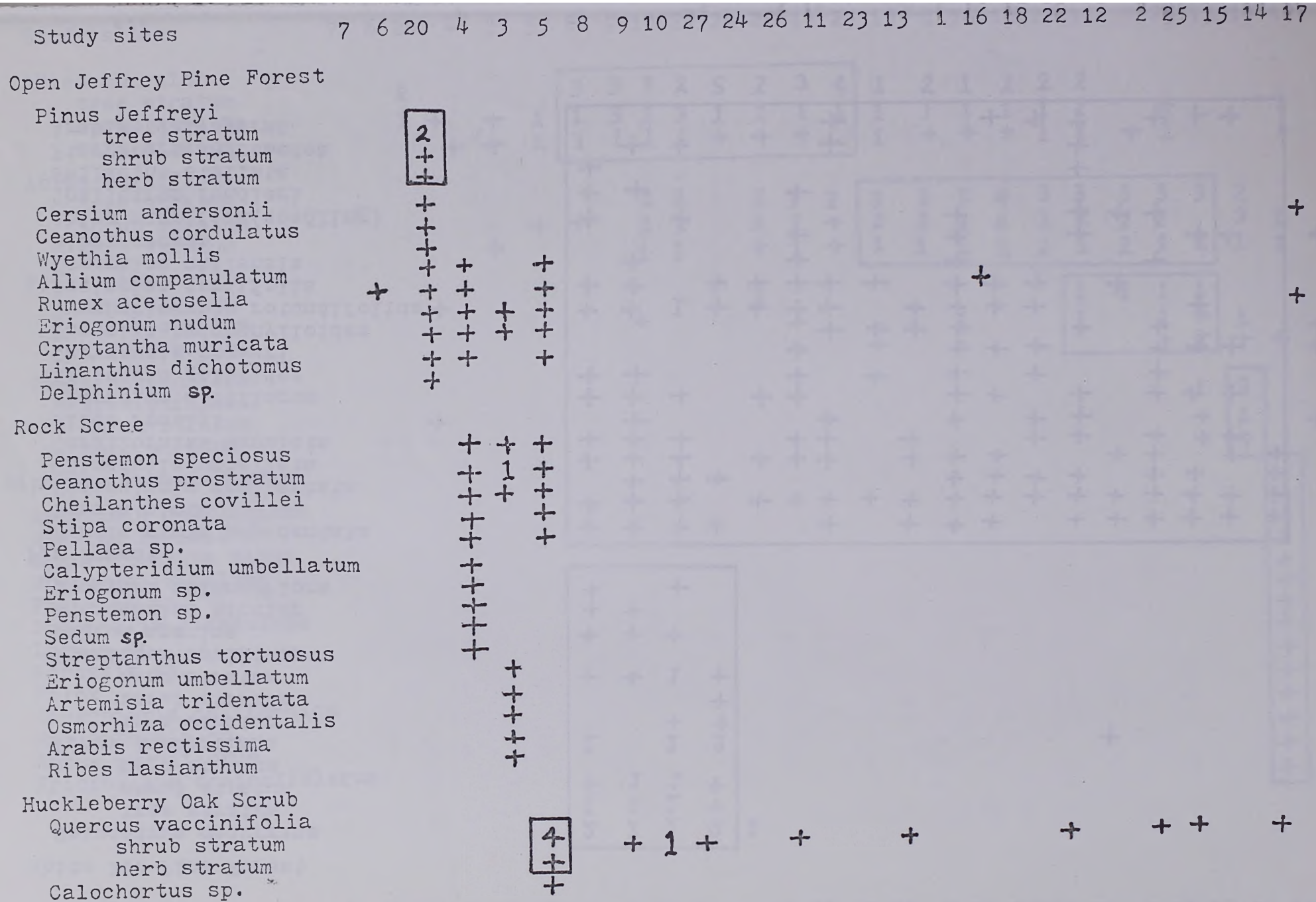
Table 1. Continued

Part B. Precipitation (1870-1930)

Month	Total Precipitation (cm)	Snow (cm)	Percent Snow (approx)
January	22.45	218.2	97
February	19.96	184.2	92
March	19.61	196.3	100
April	10.21	103.1	100
May	4.57	39.6	87
June	1.47	4.5	31
July	0.53	0	0
August	0.36	2.5	69
September	1.47	4.3	29
October	5.31	33.5	63
November	10.16	87.9	87
December	18.42	166.4	90
Year	114.76	1040.5	91

Table 2. Landscape factors and a partial list of species and potential species-releve groupings for forest, scrub, dry meadow, and scree vegetation within the Onion Creek study Candidate Research Natural Area.

Slope	7°	5	11	21	20	15	11	11	7	12	12	2	15	20	35	0	22	7	21	30	7	27	28	27	11
Aspect	300°	270	130	255	260	290	265	235	260	170	340	320	175	210	240	level	315	200	215	260	140	340	320	0	270
Elevation in meters	1,890	1,865	2,178	2,024	2,280	2,088	1,914	1,926	1,938	1,950	1,859	2,024	1,987	2,134	2,149	2,000	2,042	2,134	2,240	2,073	2,219	2,134	2,179	2,182	2,012
Study sites	7	6	20	4	3	5	8	9	10	27	24	26	11	23	13	1	16	18	22	12	2	25	15	14	17
Mountain Alder thicket																									
Alnus tenuifolia																									
shrub stratum	4																								
herb stratum	+																								
Hieracium lanatum	+																								
Delphinium polycladon	+																								
Elymus sp.	+																								
Veronica americana	+																								
Solidago occidentalis	+																								
Veratrum californicum	+																								
Habenaria sparsiflora	+																								
Solidago sp.	+																								
Hordium sp.	+																								
Mimulus (blue)	+																								
Ranunculus sp.	+																								
Achillea Lanulosa	+																								
Mimulus (yellow)	+																								
Sisyrinchium bellum	+																								
Dry Meadow																									
Capsella bursa-pastoris		+																							
Lotus micranthus		+																							
Verbascum thapsis		+																							
Madia exugua		+																							
Gilia lepdelis		+																							
Trifo[illegible]m sp.		+																							


Study sites
7 6 20 4 3 5 8 9 10 27 24 26 11 23 13 1 16 18 22 12 2 25 15 14 17
Open Jeffrey Pine Forest
Pinus Jeffreyi
tree stratum
shrub stratum
herb stratum
Cersium andersonii
Ceanothus cordulatus
Wyethia mollis
Allium companulatum
Rumex acetosella
Eriogonum nudum
Cryptantha muricata
Linanthus dichotomus
Delphinium sp.
Rock Scree
Penstemon speciosus
Ceanothus prostratum
Cheilanthes covillei
Stipa coronata
Pellaea sp.
Calypteridium umbellatum
Eriogonum sp.
Penstemon sp.
Sedum sp.
Streptanthus tortuosus
Eriogonum umbellatum
Artemisia tridentata
Osmorhiza occidentalis
Arabis rectissima
Ribes lasianthum
Huckleberry Oak Scrub
Quercus vaccinifolia
shrub stratum
herb stratum
Calochortus sp.

Study sites	7	6	20	4	3	5	8	9	10	27	24	26	11	23	13	1	16	18	22	12	2	25	15	14	17
White Fir-Pine Forest																									
Calocedrus decurrens							2	2	1	2	1														
tree stratum							1	1	2	+															
shrub stratum							+	1	1	+															
herb stratum																									
Pinus lambertiana							2		1	2										+					
tree stratum									+	+															
shrub stratum										+															
herb stratum							+	+	1	+															
Pteridium apuilinum							+	+	+																
Galium aparine							+	+																	
Adenocaulon bicolor							+																		
Goodyera oblongifolora									+																
Fir Forest																									
Pyrola picta ssp.dentata							+	+	+	+			+		+	+	+		+	+	+	+	+	+	
Pyrola picta							+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Pedicularis semibarbata								+	+	+			+			+	+	+	+		+	+		+	
Chimaphila umbellata							+	+	+		+	+	+		+	+	+			+	+		+	+	
Corallorhiza maculata							+	+	+			+	+		+			+	+		+		+		
Ribes roezlii				+				+					+			+		+	+						+
Hieracium albiflorum							+	+	+		+	+				+	+		+		+	+	+		
Kelloggia galioides							+	+				+		+		+		+			+				
Chrysopsis breweri												+				+	+	+			+	+	+		+
Phacelia hydrophylloides													+	+	+	+			+		+				+
Symphoricarpos rotundifolius			+				+	+	1	+	+	+	+		+	+	+	+				+			
Asclepias cordifolia							+	+		+	+	+	+	+		+	+	+		+					
Osmorhiza chilensis								+				+				+					+				
Ribes cereum												+				+			+				+	+	+
Abies magnifica(seedling)							+		+							+			+	+	+				
Thalictrum fendleri							+	+				+													
Smilacina stellata							+												+						
Pterospora andromedea								+	+				+						+						
Arabis platysperma			+										+				+	+	+		+	+	+	+	

Study sites	7	6	20	4	3	5	8	9	10	27	24	26	11	23	13	1	16	18	22	12	2	25	15	14	17
Abies concolor																									
tree stratum			2				3	3	3	2	5	2	3	4	1	2	1	2	2	2					
shrub stratum			1		+	1	1	3	2	3	1	2	1	1	1	1	1	1	1	2		+			1
herb stratum				+	+	1	1	1	1	1	+	+	+		1	+	+	+	1	1	+	1			1
Abies magnifica																									
tree stratum									2	2		2	1	2	3	3	3	4	3	3	3	3	3	2	
shrub stratum						+	+		2	2		2	2	+	2	3	1	2	2	2	2	2		3	1
herb stratum					+				1	1		+	1	+	1	1	1	2	2	1	2	1	1	1	1
Pinus monticola																									
tree stratum												1								1	1	1	1		
shrub stratum									+				+				1			1		1	+	1	
herb stratum													+		+		+					+	+	+	+
Tsuga mertensiana																									
tree stratum																							1	3	
shrub stratum																							+	2	
herb stratum																							+	+	
Riparian Forest Border																									1
Artemisia douglasiana																									+
Mimulus lewisii																									1
Symphoricarpos albus																									+
Rumex salicifolius																									+
Phacelia sp.																									+
Potentilla glandulosa																									+
Luzula sp.																									+
Agrostis sp.																									+
Phlox																									+
Zauschneria californica																									+
Muhlenbergia sp.																									+
Rubus parviflorus																									+
Eriophyllum confertiflorum																									+

Study sites	7	6	20	4	3	5	8	9	10	27	24	26	11	23	13	1	16	18	22	12	2	25	15	14	17
Widespread Species																									
Gayophytum ramosissimum			+						+	+			+		+		+	+	+		+				+
Monardella odoratissima			+													+		+	+		+				+
Bromus marginatus			+					+				+		+		+	+				+	+			+
Collinsia parviflora			+	+		+		+		+		+				+	+				+				
Acer glabrum																									
shrub stratum															+							+			
herb stratum				+	+	+		+						+	+				+			+		+	+
Carex sp.							+	+	+	+		+					+								
Rhamnus californica occidentalis																									
Infrequent Species																									
Arabis glabra																					+				+
Elymus sp.																+									
Lupinus sp.					+																+				
Arabis sp.	+					+																			
Poa sp.	+					+																			
Melica sp.	+		+			+												+							+
Prunus emarginata																									
shrub stratum									+																
herb stratum									+																
Lilium sp.									+																
Aster sp.												+													+
Gentiana sp.			+			+																			+
Arctostaphylos nevadensis																									

Table 3. Count-plot data for coniferous species within 0.7 ha plots which were infrequently encountered within the Onion Creek study area.

Calocedrus decurrens

Plot No.	Frequency (stems/ha)	% Cover	Basal Area (m^2/ha)	Importance Value
5	72	0.5	0.1	8
8	12	30	62	106
9	129	20	36	73
10	244	9	12	32
24	14	16	6	23
26	29	13	32	47
27	14	1	0.3	1

Pinus lambertiana

Plot No.	Frequency (stems/ha)	% Cover	Basal Area (m^2/ha)	Importance Value
8	14	7	13	22
9	43	15	29	50
10	115	5	11	21
12	29	15	15	34
13	29	7	1.4	12
26	14	6	25	34
27	72	13	20	39

Pinus Jeffreyi

Plot No.	Frequency (stems/ha)	% Cover	Basal Area (m^2/ha)	Importance Value
5	14	0.5	0.1	5
10	29	0.5	1	2.4

Table 3. (cont.)

Pinus Jeffreyi (cont.)

Plot No.	Frequency (stems/ha)	% Cover	Basal Area (m^2/ha)	Importance Value
20	29	19	62	93
24	14	0.5	1	2.1
27	43	12	16	33

Tsuga mertensiana

Plot No.	Frequency (stems/ha)	% Cover	Basal Area (m^2/ha)	Importance Value
14	144	55	22	137
15	57	5.5	16	62

Table 4. Suggested Age-Diameter Classes for Abies concolor and A. magnifica at Onion Creek Study Sites.

Age-Class	Size Class by Species			
	Abies concolor		Abies magnifica	
	Average Sites[1]	Exceptional Sites[2]	Average Sites[3]	Exceptional Sites[4]
0-50 yrs	0-137cm ht	0-8cm dbh	0-122cm ht	0-8cm dbh
51-100	137 cm-12cm dbh	8 - 53	122cm ht to 10cm dbh	8 - 27
101-150	12 - 36	55 - 91	10 - 23	27 - 50
151-200	36 - 66	91 - 117	23 - 42	50 - 73
201-250	66 - 95*[5]	117 - 137*	42 - 60	73 - 97*
251-300	95 - 114*	137 - 153*	60 - 82*	97 - 117*
301-350	114 - 130*	153 - 166*	82 - 102*	117 - 136*
351-400	130 - 143*	166 - 178*	102 - 116*	136 - 150*
401	143*	178*	116*	150*

Age-diameter relationship for A. concolor at study sites 1,5,10-13,16, 18,23,26, and 27.

Age-diameter relationship for A. concolor at study sites 8,9,20, and 24.

Age-diameter relationship for A. magnifica at study sites 1,2,5,11-16,18, 22, 25, and 26. Relationship is also used for Tsuga mertensiana at site 14 and for Pinus monticola at sites

Table 4. continued

4 Age-diameter relationship for A. magnifica at study sites 8-10,24,and 27.

5 Asterisks indicate estimates of diameter for a given age-class based upon the previous nature of the age-diameter relationship.

Table 5. Density per age-class for coniferous species with relatively limited distributions within the Onion Creek study area.

AGE CLASS	DENSITY (stems/ha) Tsuga mertensiana[1]	Pinus Jeffreyi (forest)[2]	Pinus Jeffreyi (open)[3]	Calocedrus decurrens[4]
1 (0-50 yrs)	243	43	214	229
2 (51-100 yrs)	86	29	0	20
3 (101-150 yrs)	30	14	0	3
4 (151-200 yrs)	43	0	0	6
5 (201-250 yrs)	0	0	0	0
6 (251-300 yrs)	14	0	0	0
7 (301-350 yrs)	30	14	29	14
8 (351-400 yrs)	0	0	0	0
9 (400 yrs)	0	0	0	14

1 Data from plot 14.

2 Data from plots 10 and 27.

3 Data from plot 20.

4 Data from plots 8, 9, 10, 24, and 27.

Table 6. Density per age-size class of conifers at selected plots within the Onion Creek study area.

Density (stems/ha)

Plot 27

Age-Size Class	Abies magnifica	Abies concolor	Calocedrus decurrens	Pinus lambertiana	Pinus jeffreyi
1	186	2,150	43	29	29
2	14	1,058	0	114	29
3	43	143	0	14	0
4	14	43	14	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	14	14	14
8	0	0	0	0	0
9	0	0	0	0	0

Plot 24

Age-Size Class	Abies magnifica	Abies concolor	Calocedrus decurrens	Pinus jeffreyi
1	0	229	0	0
2	0	1,244	0	14
3	14	72	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	14	0
8	0	0	0	0
9	0	0	0	0

Table 6. continued.

	Density (stems/ha)				
	Plot 12			Plot 2	
ge-Size Class	Abies magnifica	Abies concolor	Pinus lambertiana	Abies magnifica	Pinus monticola
1	415	157	0	4,976	72
2	1,401	358	29	214	29
3	858	86	14	14	14
4	272	0	0	14	14
5	14	0	0	43	14
6	14	0	0	57	0
7	0	0	14	14	0
8	0	0	0	14	0
9	14	0	0	0	0

	Plot 23		Plot 22	
ge-Size Class	Abies magnifica	Abies concolor	Abies magnifica	Abies concolor
1	72	14	7,794	972
2	0	14	443	86
3	14	114	43	57
4	14	72	43	0
5	0	100	14	14
6	14	29	29	14
7	29	0	29	0
8	0	0	14	0
9	0	0	14	0

Table 6. continued.

Age-Size Class	Density (stems/ha) Plot 20 Abies magnifica	Abies concolor	Pinus jeffreyi
1	114	2,187	200
2	0	100	0
3	0	14	0
4	0	0	29
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0

Table 7. Potential Solar Beam Irradiation of Typical Slope-Aspect Combination for Onion Creek Forest, Scrub, and Meadow Cover Types.[1]

Potential Solar Beam Irradiation by Cover Type

Cover type	Tsuga mertensiana Abies magnifica	Abies magnifica Pinus monticola			Abies magnifica Abies concolor		
Aspect	N	N	NNW	NW	S	SW	W
Slope %	40%	40%	40%	50%	30%	40%	45%
June 22[2]	965 Ly/day	965	963	934	981	979	981
May 3, Aug 10	781	781	788	779	949	943	893
Mar 31, Sept 23	433	433	459	485	842	825	692
Feb 7, Nov 5	137	137	173	220	673	645	461
Dec 22	32	32	59	107	564	535	339
Total[3]	172.3	172.3	179.4	185.8	296.1	290.1	248.7
RI[4]	0.33	0.33	0.34	0.35	0.56	0.55	0.47

Cover type	Abies concolor Abies magnifica		Abies concolor Pinus Jeffreyi	Abies concolor, Pinus lambertiana Pinus Jeffreyi, Calocedrus decurrens
Aspect	S	SE-SW	W	SW
Slope %	30%	40%	30%	15%
June 22	981	979	1002	1013
May 3, Aug 10	949	943	909	940
Mar 31, Sept 23	842	825	698	759
Feb 7, Nov 5	673	645	460	538
Dec 22	564	535	335	416

Table 7. continued

Aspect	S	SE-SW	W	SW
Total	296.1	290.1	251.4	270.8
RI	0.56	0.55	0.48	0.52

Cover type	Pinus Jeffreyi (open forest)		Dry Meadow		Quercus vaccinifolia			Scree			
Aspect	S	SSE	SW		W	SSW	S	W	SW	SSW	S
Slope %	30%	40%	10% (low elev)	30% (high elev)	60%	50%	70%	60%	70%	50%	50%
June 22	981	962	1018	996	957	935	860	957	914	935	925
May 3, Aug 10	949	945	936	946	875	935	894	875	914	935	930
Mar 31, Sept 23	842	860	742	804	684	879	914	684	855	879	892
Feb 7, Nov 5	673	706	513	608	462	748	845	462	721	748	776
Dec 22	564	603	389	493	343	652	767	343	626	652	682
Total	296.1	300.9	265.7	284.1	245.3	306.4	315.7	245.3	297.6	306.4	310.4
RI	0.56	0.57	0.51	0.54	0.47	0.58	0.60	0.47	0.57	0.58	0.59

---

1 Data derived or interpolated from Frank and Lee (1966) using tables for 40°N Latitude.

2 Potential solar beam irradiation in Langleys per day for representative dates listed.

3 Total potential solar beam irradiation per year in thousands of Langleys.

4 RI = Radiation Index, the percent of potential sunlight striking a unit surface over one year.

FIGURE CAPTIONS

Figure 1. Topographic gradients and location of 0.07 ha study sites within Onion Creek Candidate Research Natural Area.

Figure 2. Distribution of vegetation types within Onion Creek Candidate Research Natural Area. Letters stand for names of dominant species or cover types: Ac, *Abies concolor*; Ag, *Acer glabrum*; Am, *Abies magnifica*; An, *Arctostaphylos nevadensis*; Ap, *Arctostaphylos patula*; At, *Alnus tenuifolia*; Cc, *Ceanothus cordulatus*; Ld, *Calocedrus* (*Libocedrus*) *decurrens*; M, dry meadow; Qv, *Quercus vaccinifolia*; Pj, *Pinus Jeffreyi*; Pl, *Pinus lambertiana*; Pm, *Pinus monticola*; Pt, *Populus tremuloides*; Tm, *Tsuga mertensiana*; S, rock scree.

Figure 3. Count-plot data for arboreal species within 0.07 ha plots within Onion Creek Candidate Research Natural Area.

Figure 4. Age-height relationships for seedling *Abies magnifica* and *A. concolor* at selected study sites within the Onion Creek study area.

Figure 5. Age-height relationships for sapling *Abies concolor* at selected study sites within the Onion Creek study area. Dotted line represents saplings growing on very steep topography.

Figure 6. Age-height relationships for sapling *Abies magnifica* at selected study sites within the Onion Creek study area. Dotted lines represent growth of saplings on very steep (plot 13) or densely shaded terrain (plot 12).

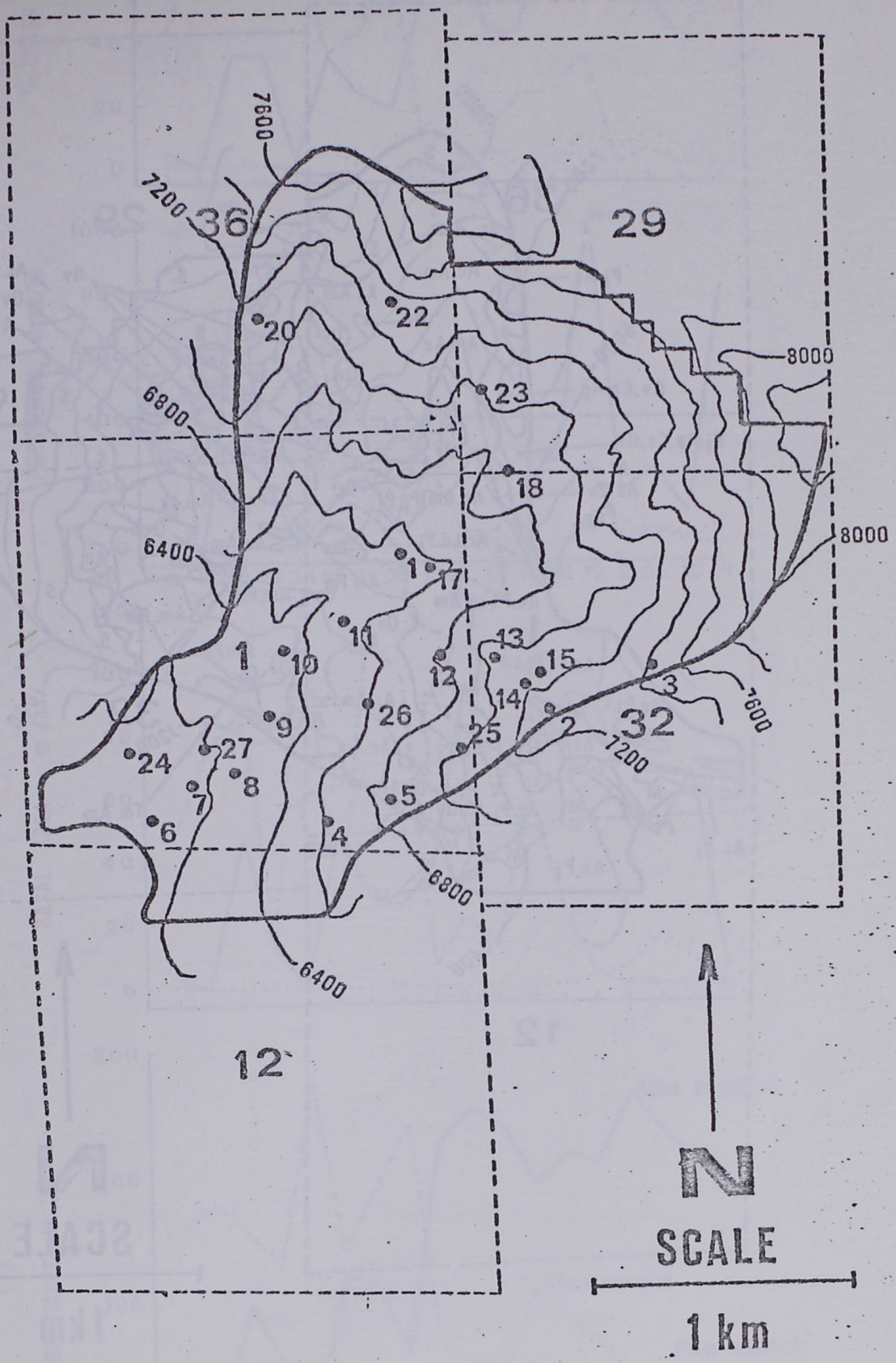
Figure 7. Age-height relationship for *Abies magnifica* and *A. concolor* within the Onion Creek study area. Numbers represent plots for representative trees. Age was determined at breast height (1.4 m) and height is standardized to 100 years at breast height to give a site index.

Figure 8. Age-diameter relationship for *Abies concolor* and *A. magnifica* within the Onion Creek study area. Diameters and ages were measured at breast height (1.4 m). Numbers indicate plots from which trees were sampled.

Figure 9. Survivorship curves for *Abies concolor*, *Abies magnifica*, *Pinus lambertiana*, and *Pinus monticola* within white fir forest (A) and red fir forest (B). Diameters for various age classes are given in Table 4.

Figure 10. Probable interrelationships between plant communities within Onion Creek Candidate Research Natural Area. Arrows indicate changes in vegetative composition taking place with changing physiographic or other factors listed. Decreased exposure reduces fall, winter, and spring potential solar beam irradiation (PSBR), compensating for moisture and enabling prolonged accumulation of snow. High exposure is correlated with shorter periods of snow cover.

Figure 1


7600
7200
36
29
22
20
8000
23
6800
18
8000
6400
1
17
11
13
10
12
15
1
3
7600
14
26
9
25
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27
24
8
7
5
6
4
6800
6400
12
N
SCALE
1 km

Figu

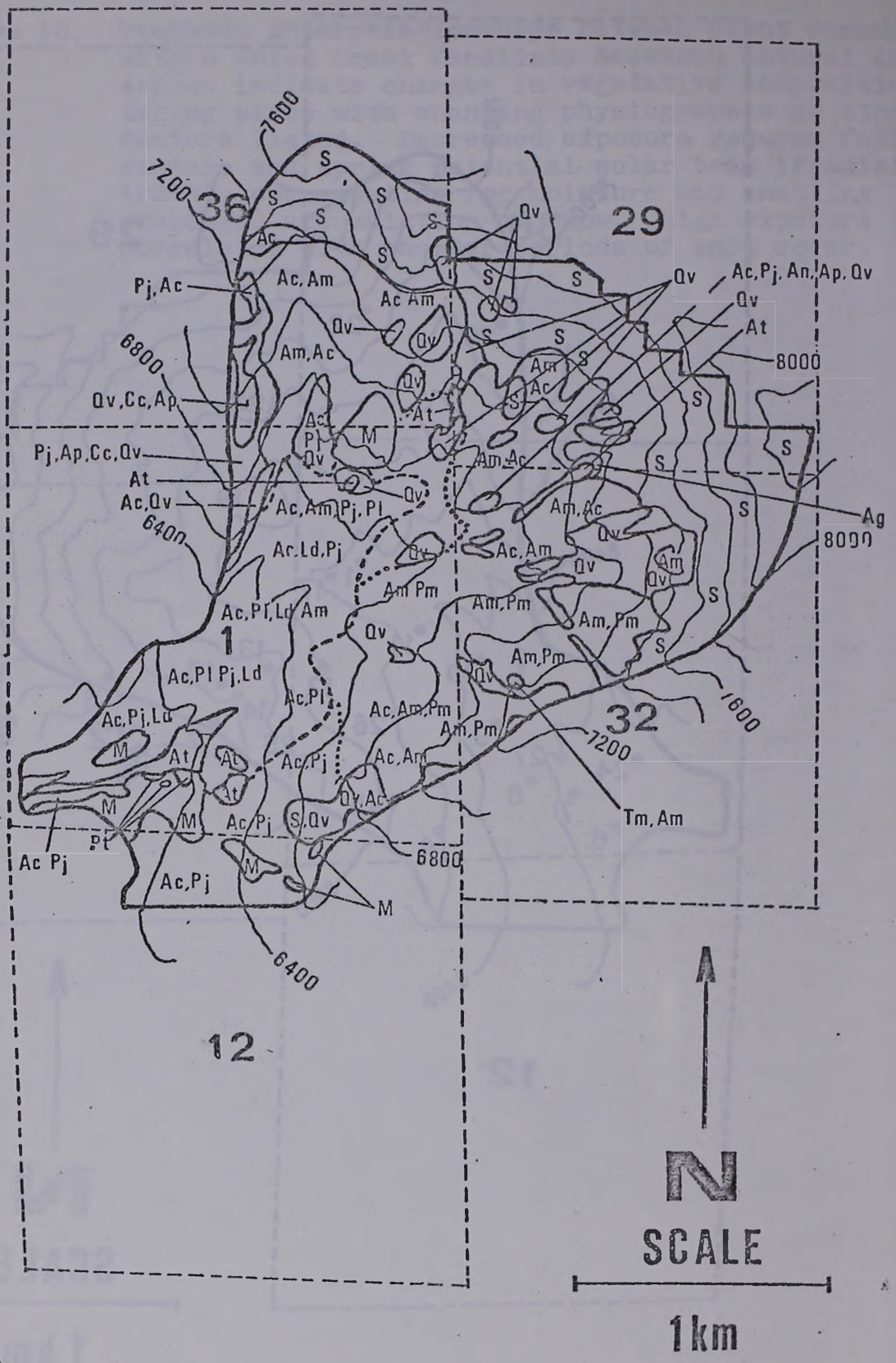
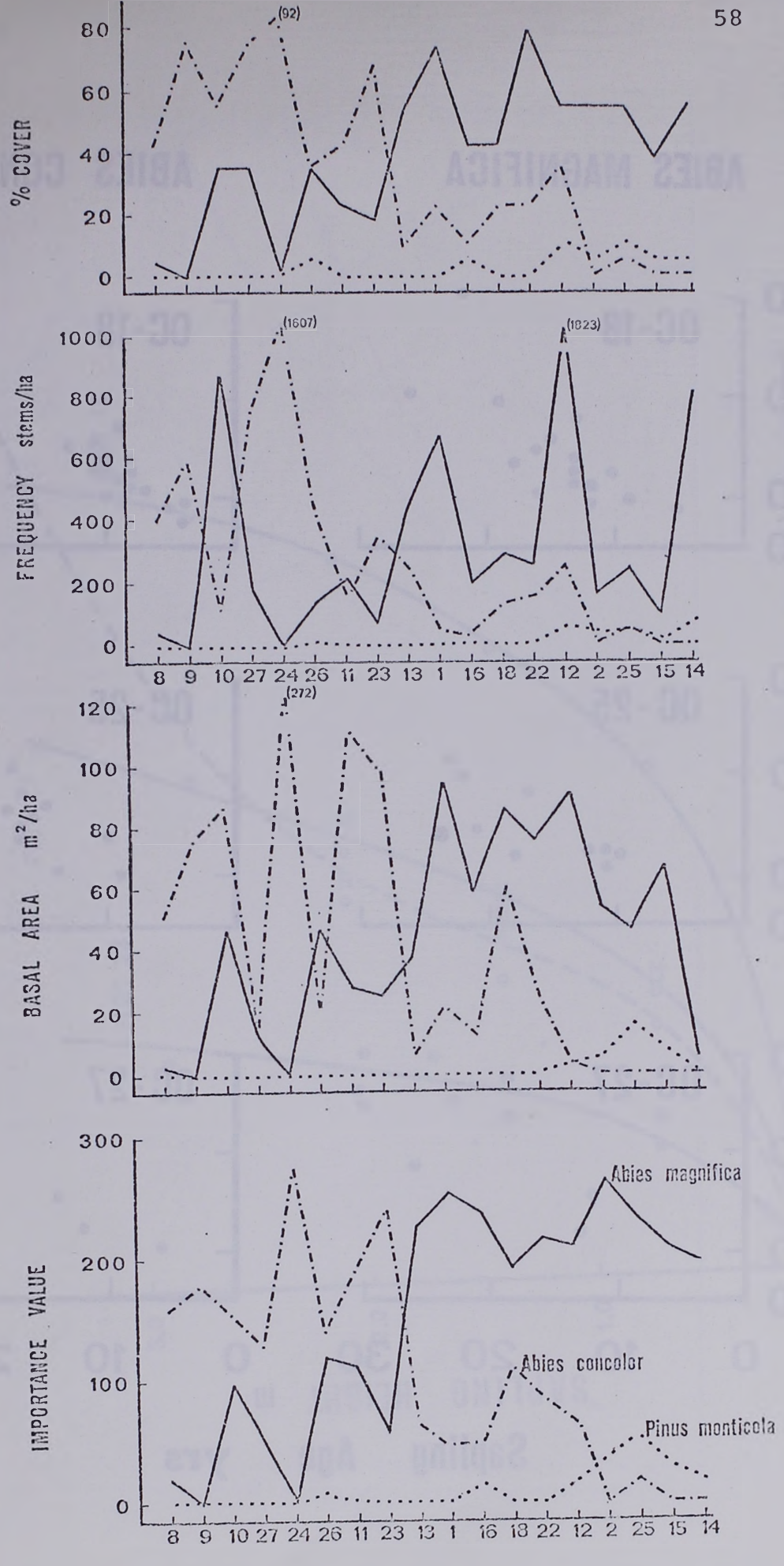
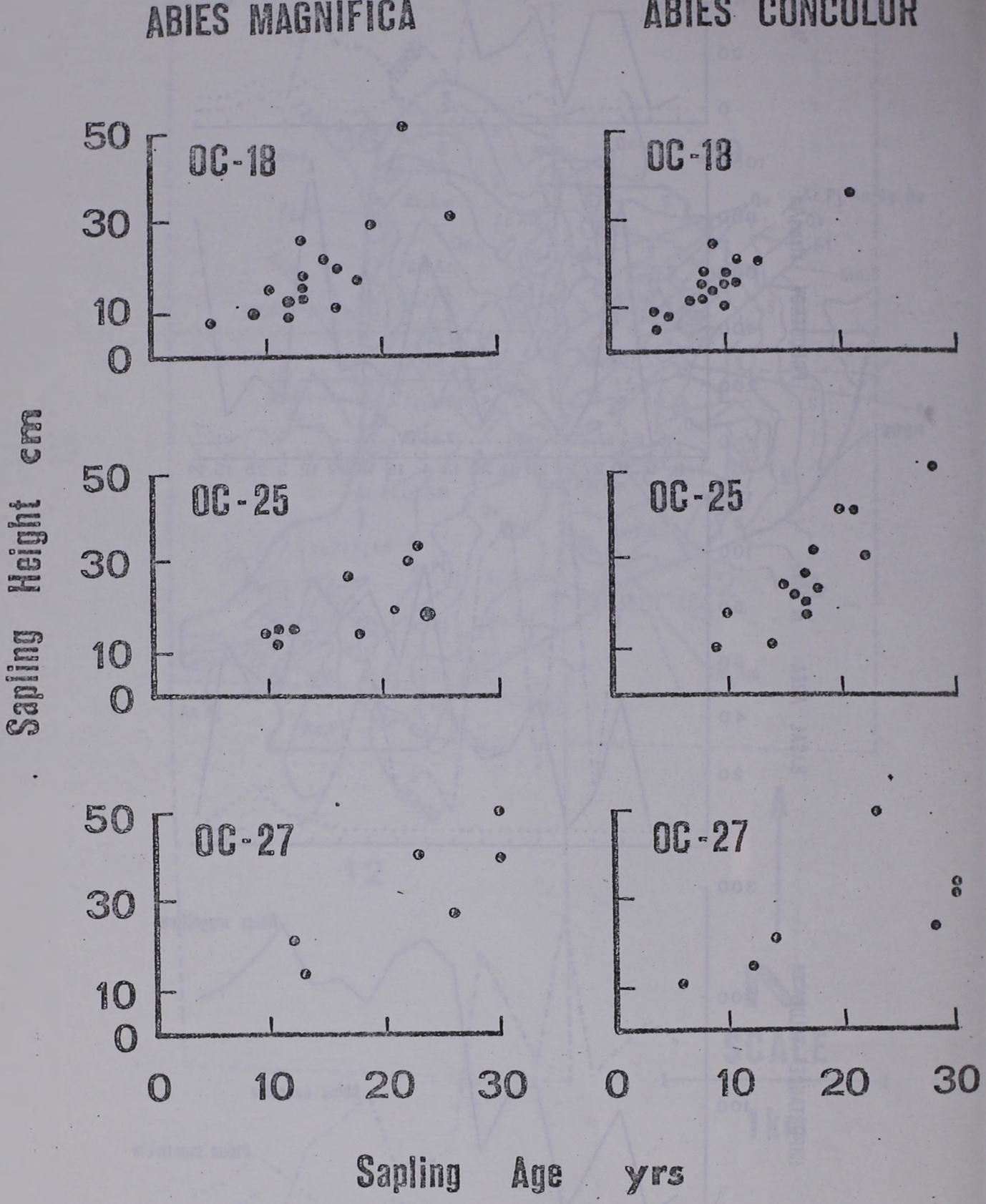
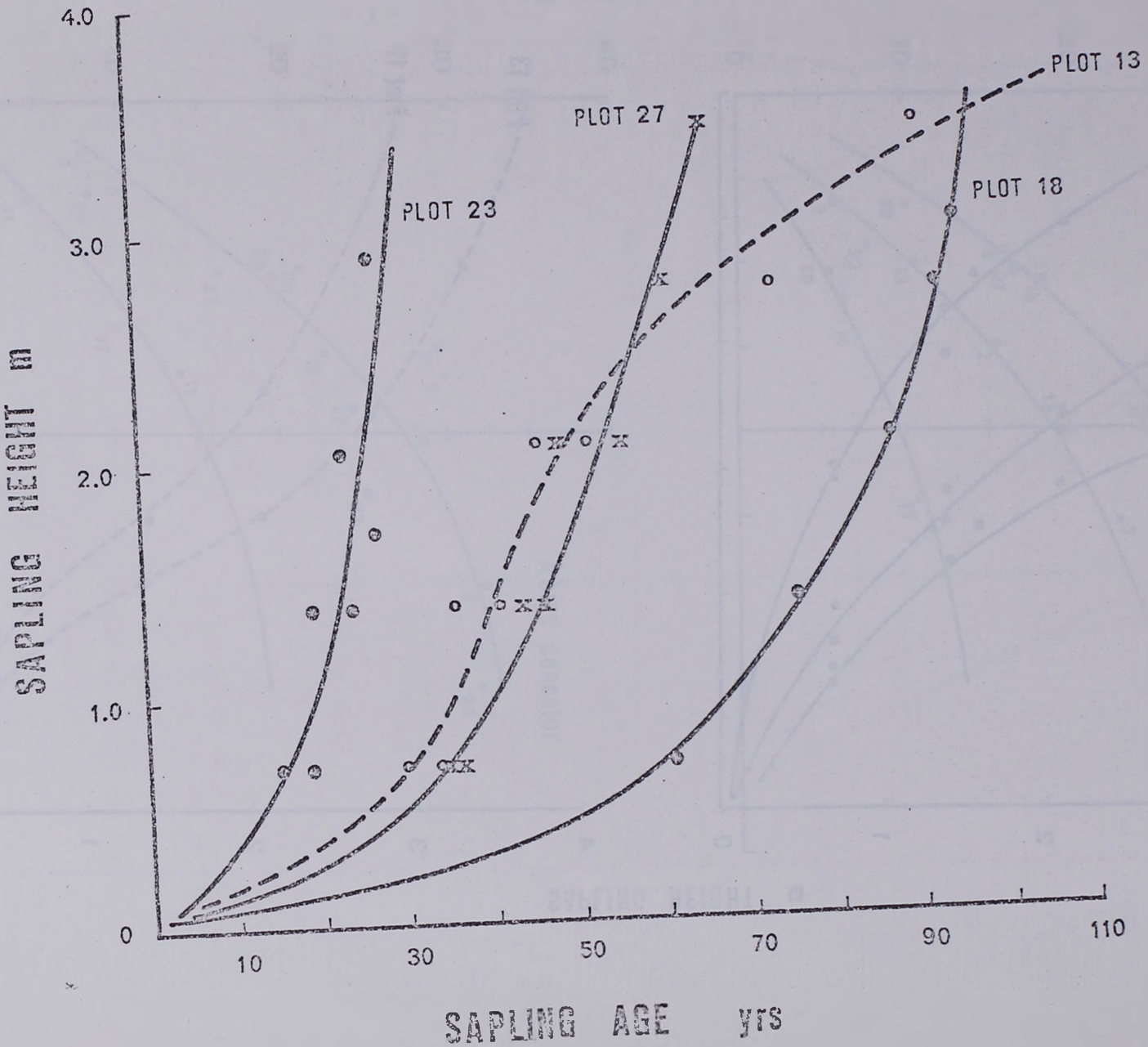

36
29
32
1
12
7600
7200
6800
6400
8000
1600
Pj,Ac
Ac,Am
Ac Am
Am,Ac
Qv,Cc,Ap
Pj,Ap,Cc,Qv
At
Ac,Qv
Ac,Am,Pj,Pl
Ac,Ld,Pj
Ac,Pl,Ld Am
Ac,Pl Pj,Ld
Ac,Pj,Ld
Ac,Pl
Ac,Pj
Ac,Am,Pm
Am,Pm
Ac,Am
Qv,Ac
S,Qv
Ac Pj
Tm,Am
Qv
Ac,Pj,An,Ap,Qv
At
Ag
M
S
Ac
Pl
Pj
Am
Qv
N
SCALE
1km

Figure 3


% COVER
(92)
FREQUENCY stems/ha
(1607)
(1823)
BASAL AREA m²/ha
(272)
IMPORTANCE VALUE
Abies magnifica
Abies concolor
Pinus monticola
8 9 10 27 24 26 11 23 13 1 16 18 22 12 2 25 15 14
PLOT NUMBER

Figure


ABIES MAGNIFICA
ABIES CONCOLOR
OC-18
OC-18
OC-25
OC-25
OC-27
OC-27
50
30
10
0
Sapling Height cm
0
10
20
30
Sapling Age yrs


4.0
3.0
2.0
1.0
0
SAPLING HEIGHT m
PLOT 13
PLOT 27
PLOT 18
PLOT 23
10
30
50
70
90
110
SAPLING AGE yrs

Figure

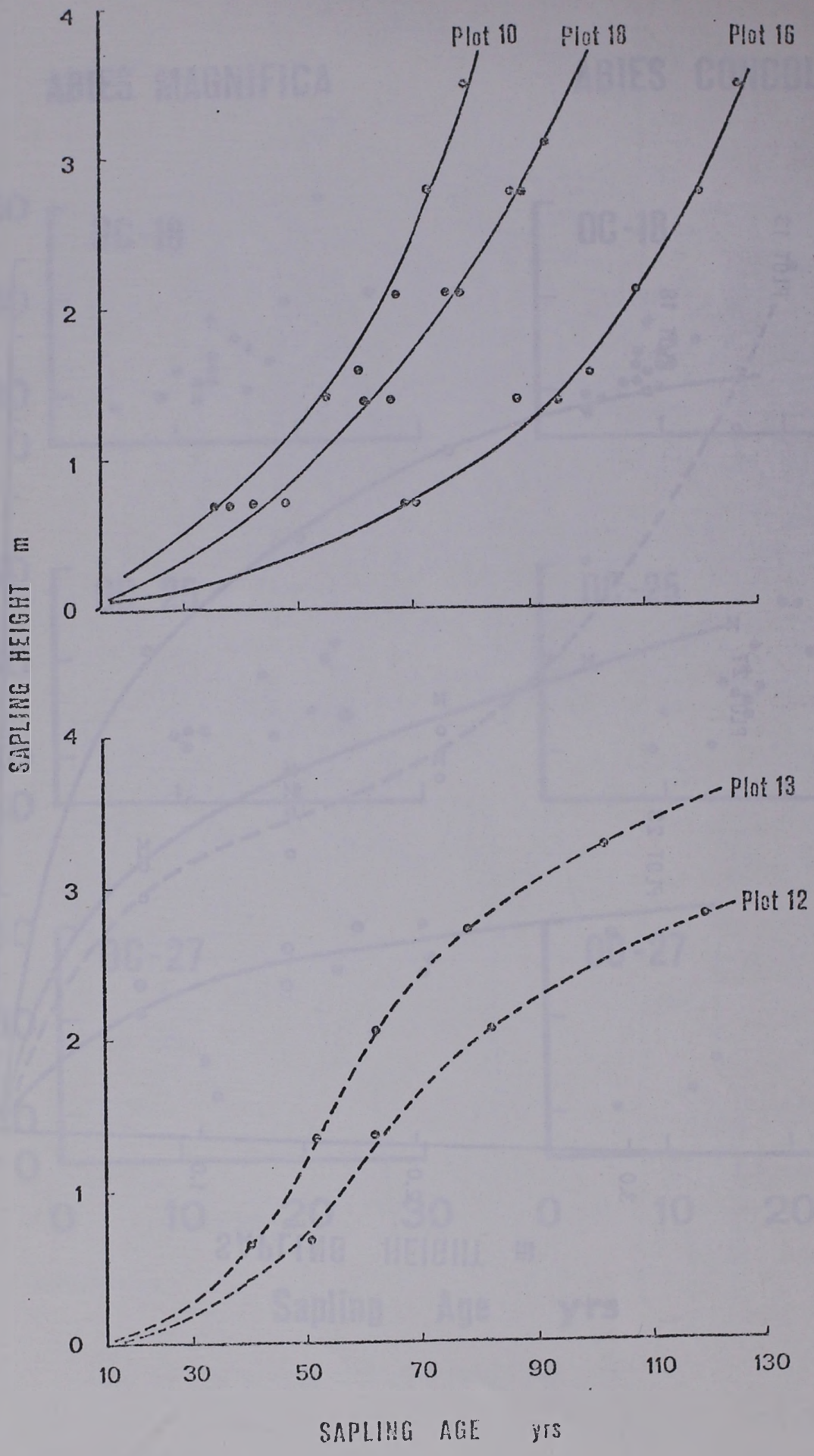
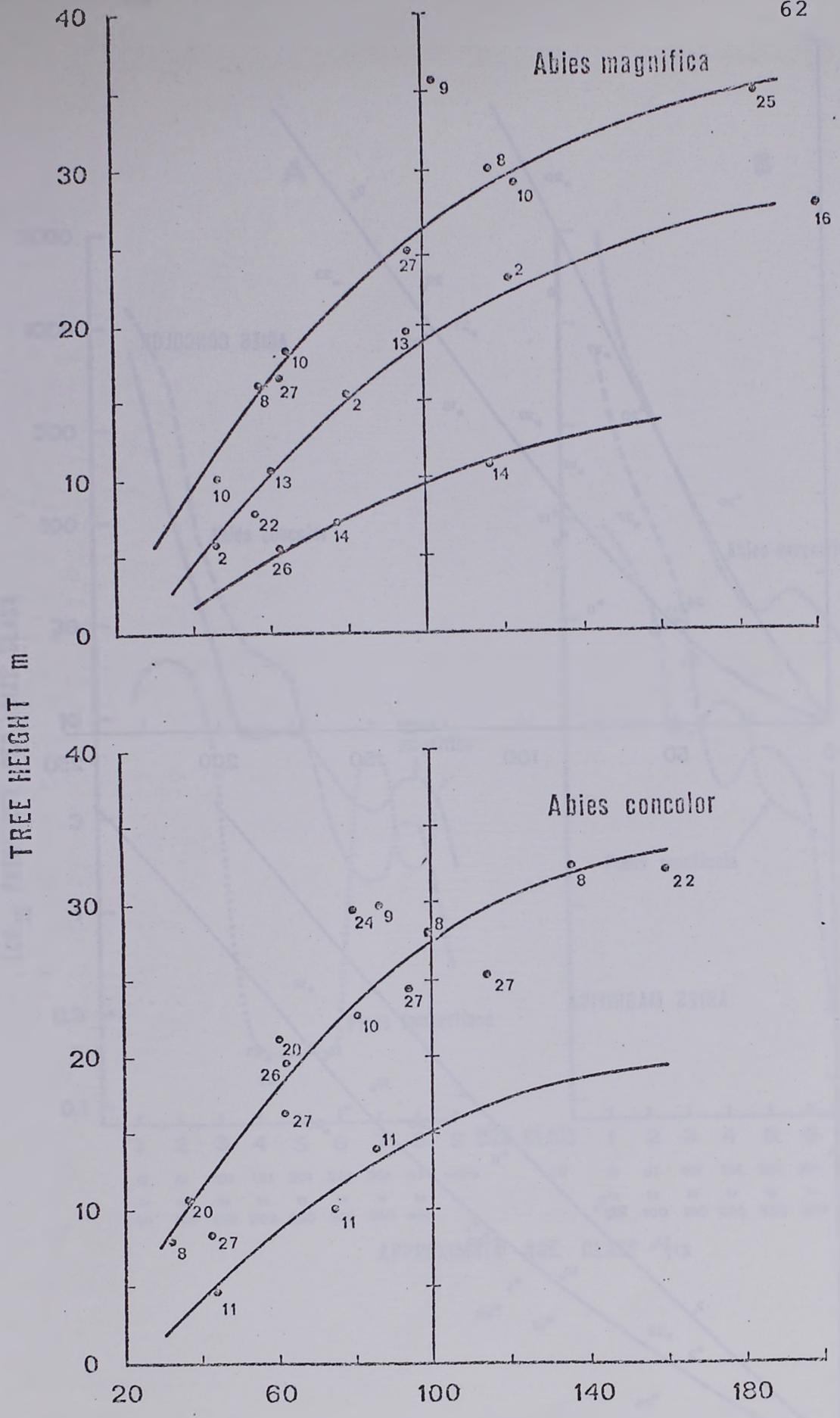

Plot 10
Plot 18
Plot 16
Plot 13
Plot 12
SAPLING HEIGHT m
SAPLING AGE yrs
0
1
2
3
4
10
30
50
70
90
110
130

Figure 7


Abies magnifica
Abies concolor
TREE HEIGHT m
AGE AT BREAST HEIGHT yrs
0
10
20
30
40
20
60
100
140
180

Figur

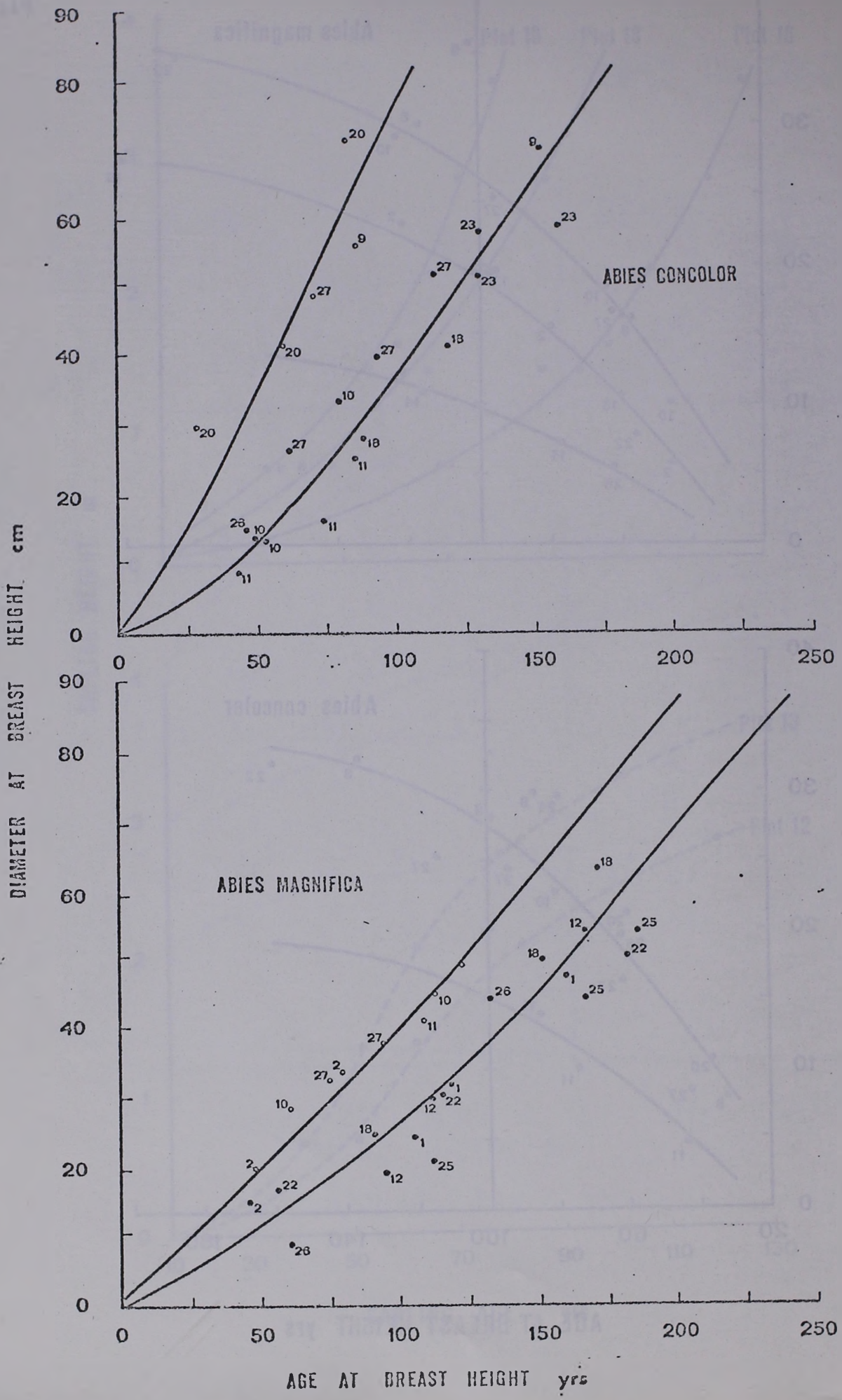

ABIES CONCOLOR
ABIES MAGNIFICA
DIAMETER AT BREAST HEIGHT cm
AGE AT BREAST HEIGHT yrs
0
20
40
60
80
90
0
50
100
150
200
250

Figure 9

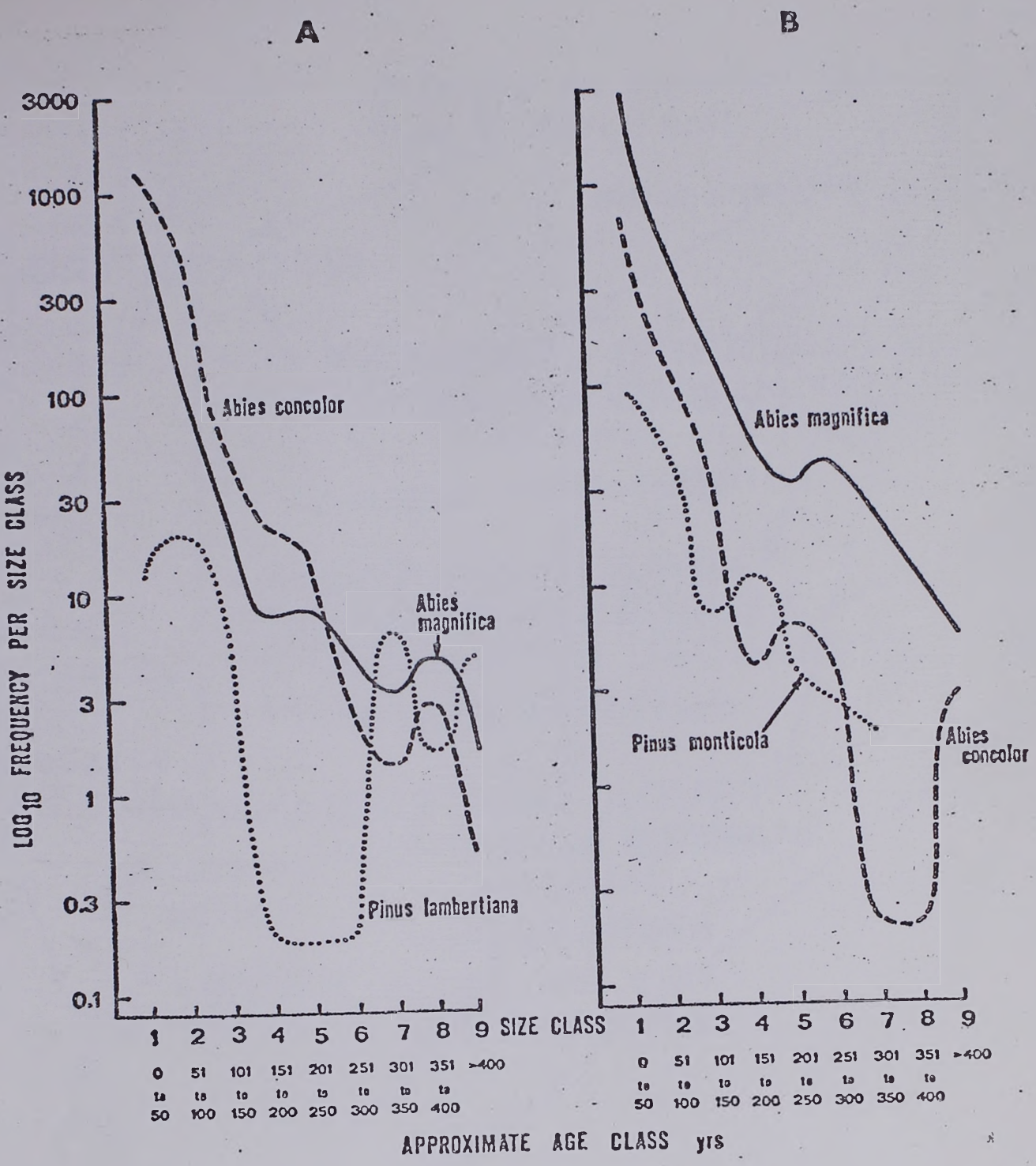
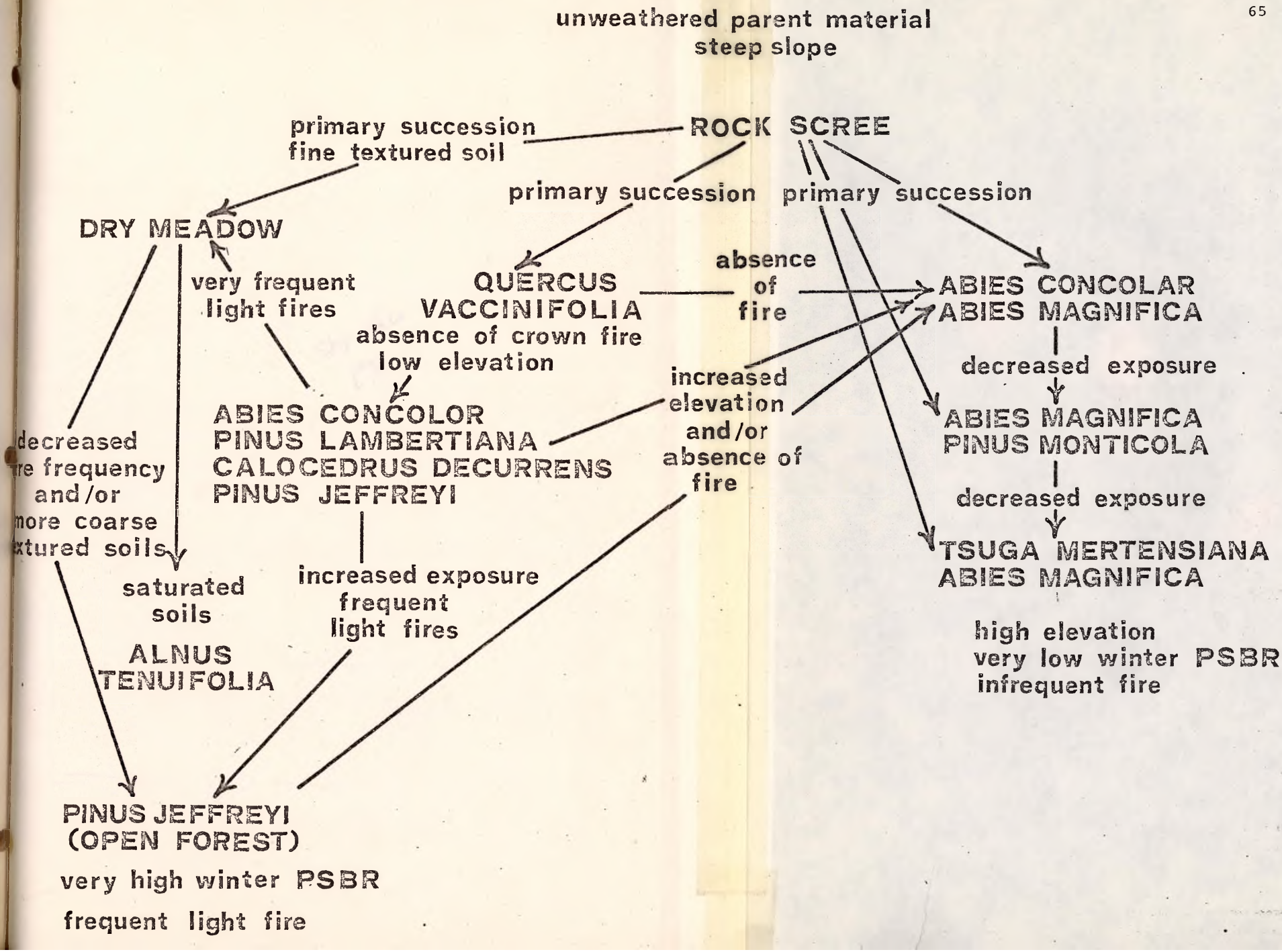

A
B
3000
1000
300
100
30
10
3
1
0.3
0.1
LOG10 FREQUENCY PER SIZE CLASS
Abies concolor
Abies magnifica
Pinus lambertiana
Abies magnifica
Pinus monticola
Abies concolor
1 2 3 4 5 6 7 8 9 SIZE CLASS
0 to 50
51 to 100
101 to 150
151 to 200
201 to 250
251 to 300
301 to 350
351 to 400
>400
APPROXIMATE AGE CLASS yrs

Figure 10


unweathered parent material
steep slope
ROCK SCREE
primary succession
fine textured soil
primary succession
primary succession
DRY MEADOW
very frequent
light fires
QUERCUS
VACCINIFOLIA
absence of crown fire
low elevation
absence
of
fire
ABIES CONCOLAR
ABIES MAGNIFICA
decreased exposure
ABIES MAGNIFICA
PINUS MONTICOLA
decreased exposure
TSUGA MERTENSIANA
ABIES MAGNIFICA
high elevation
very low winter PSBR
infrequent fire
ABIES CONCOLOR
PINUS LAMBERTIANA
CALOCEDRUS DECURRENS
PINUS JEFFREYI
increased
elevation
and/or
absence of
fire
decreased
re frequency
and/or
more coarse
xtured soils
saturated
soils
ALNUS
TENUIFOLIA
increased exposure
frequent
light fires
PINUS JEFFREYI
(OPEN FOREST)
very high winter PSBR
frequent light fire